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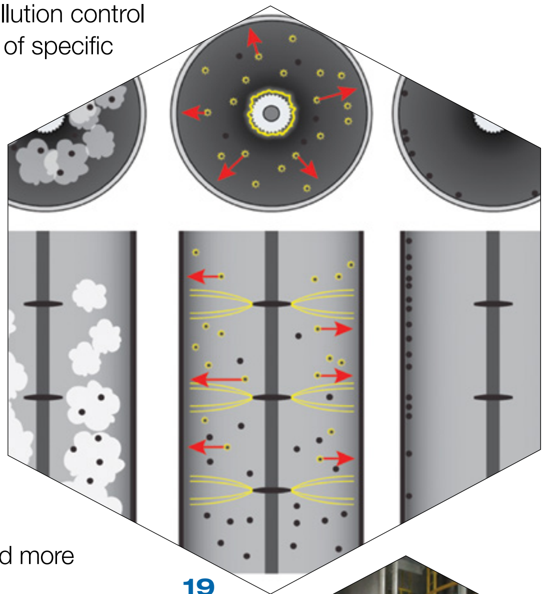
Technical and Practical



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CHEMICAL ENGINEERING
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Editor's Page

People drive digital success

In 1851, the year that the first America's Cup sailboat race was contested, the top speed for a wind-powered vessel was 10 knots. Over the next 100 years, top sailboat speeds barely budged, but by the mid-1970s, top sailing speed had increased to near 40 knots. And driven by innovations in materials, vessel design and sailor training, current America's Cup boats routinely "fly" on hydrofoils at triple or quadruple wind speeds, and can surpass 60 knots.

At the recent Connected Plant Conference (www.connectedplant-conference.com) in Houston, keynote speakers Rod Walker and Kristen Etheredge, partners at the consulting firm Kearney (Chicago, Ill.; www.kearney.com), described the dramatic and rapid improvement in sailboat performance to illustrate the accelerating pace of change in many fields that affect modern life.

"Most of us are focused on meeting day-to-day objectives, so we don't always appreciate the speed of change happening around us," says Walker, "and we don't take the actions toward transformative change — the things that will make those boats fly."

Walker and Etheredge discussed organizational change management and shifting company culture in the context of deploying digitalization tools at industrial facilities. Leveraging digital tools, including artificial intelligence, has become an essential element of the business of chemical manufacturing (and most other industry sectors as well), rather than a "nice-to-have" feature. But the difference between success and failure of digital deployments comes down to how well the workers adopt and embrace the digital tools.

Walker says 70% of digitalization projects ultimately fail, and most often, the reason has nothing to do with the capabilities of the technology, but because organizations fail to win the commitment of employees. When trying to make changes to business processes, such as those required in a digital transformation, "leaders often believe workers will respond logically to changes, but the reality is that they don't," Etheredge explains. "Human emotions are going to have an outsized influence on whether and how digital tools are adopted and used."

Organizational culture can be thought of as the behaviors that are rewarded, and those that are tolerated, Etheredge argues, and if those behaviors are not aligned with the business results, then organizational changes, such as digital deployments, will not have good success.

"You have to be transparent in addressing questions of why the change is necessary," Etheredge says, "and clearly and specifically articulate how the technological change will benefit individual workers — the 'what's-in-it-for-me?' question."

One thing that has become clear in examining the data and analysis on organizational change management is that when companies carefully consider and address the "human aspects" of change upfront and throughout a change project, they see a significant return on investment. Specifically, Walker said that top culture performers deliver expected results five times as often as those with lower scores.

For successful digital transformation initiatives, you need to generate enthusiasm for the change by communicating the vision clearly, supporting changes in capabilities, deepening commitment on the part of workers, and, once the changes take hold, sustaining performance, the speakers say.

Whether your objective is sailing a faster boat, or manufacturing a new chemical product safely, sustainably and profitably, getting the people part right is a key to success. ■

Scott Jenkins, senior editor

Chementator

Edited by:
Gerald Ondrey

Reducing CO_2 to formic acid

A research team led by Kenneth C. Neyerlin at the National Renewable Energy Laboratory (NREL; Golden, Colo.; www.nrel.gov), with members from Argonne National Laboratory (Lemont, Ill; www.anl.gov) and Oak Ridge National Laboratory (Tenn.; www.ornl.gov) has developed a membrane electrode assembly (MEA) for the efficient electrochemical reduction of CO_2 into formic acid.

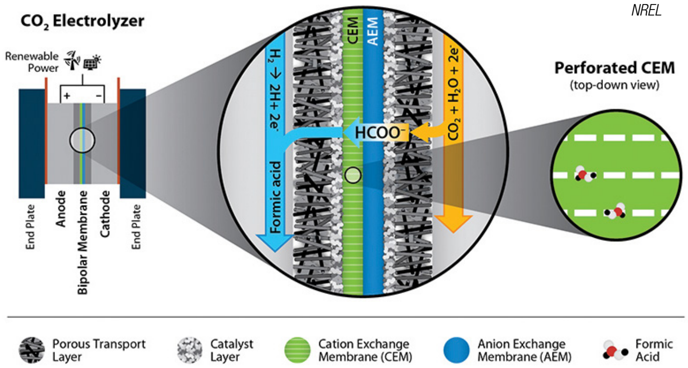
The MEA in an electrolyzer cell typically includes an ionically conductive membrane (cation or anion exchange) pressed between two electrodes consisting of electrocatalysts and ionically conducting polymers. Leveraging the team's experience in fuel cells and water electrolysis technology, they investigated several MEA configurations in an electrolyzer cell to compare electrochemical reduction of CO_2 to formic acid.

As described in a recent issue of *Nature Communications*, the key technological advancement is a perforated cation-exchange membrane (diagram), which, when utilized in a forward-bias, bipolar-membrane configuration, allows formic acid generated at the membrane interface to exit through the anode flow field. This perforated membrane helped achieve stable, high-selectivity formic acid production, and it simplifies the design by using off-the-shelf components, according to the authors.

"The result of this study is a paradigm shift in the electrochemical production of organic acids like formic acid," Neyerlin says. "The perforated membrane architecture reduces the complexity of previous designs and can also be leveraged to improve energy efficiency and durability for other electrochemical CO_2-conversion devices."

Formic acid is a potential intermediate chemical with a wide range of applications, especially as a raw material for the chemical or biomanufacturing industries. Formic acid has also been identified as an input for biological upgrading into sustainable aviation fuel (SAF).

NREL



This patented process improves grease handling

Calcium-sulfonate complex greases are widely used in applications in the pulp-and-paper, marine and steel-manufacturing sectors. Within an ever-volatile lithium market, calcium-sulfonate greases are increasingly seen as a reliable alternative to lithium-based greases.

However, typical methods for preparing high-performance calcium-sulfonate grease complexes require hazardous chemicals, such as acetic acid and isopropyl alcohol (IPA), which require special environmental, health and safety (EHS) considerations, and even different handling equipment in some cases. To avoid such processing and handling challenges, Afton Chemical Corp. (Richmond, Va.; www.aftonchemical.com) has patented a new production process for calcium-sulfonate greases that will help to ease the transition away from lithium-based greases, while also trying to minimize EHS concerns. "Afton's patented process for manufacturing calcium sulfonate complex grease uses HiTEC 557, a 300 TBN calcium sulfonate, along with complexing agents, promoters and other standard grease raw materials. Unlike conventional processes, Afton's process does not use aggressive acids like acetic acid. It is also brings value by being highly repeatable, with very little batch-to-batch variation in quality and yield, and decreases production time compared to other conventional calcium-sulfonate complex grease processes," explains Alyson Wilson, industrial marketing specialist at Afton Chemical.

The key to the new process is a specialized promoter material, which replaces IPA, while still exhibiting similar transparency, brightness and performance properties. "This new promoter system is used to convert amorphous calcium carbonate into its crystalline form, which causes the rheology of the mixture to gel," says Wilson. The process has now been expanded to industrial-scale production and is being deployed by grease manufacturers commercially.

LIME INJECTION

Engineers at the Institute for Technologies of Metals (ITM) at the University of Duisburg-Essen (Duisburg, Germany; www.uni-due.de), together with Fritz Winter Eisengießerei GmbH & Co. KG (FW; Stadtallendorf; Germany) and the FEhS – Building Materials Institute e.V. (Duisburg) have developed a process that allows molten iron to be desulfurized to produce spheroidal graphite cast iron without using magnesium. Their results, published in the *Journal of Sustainable Metallurgy*, make it possible for ironmakers to use local sources of lime instead of relying on imports of magnesium, 87% of which comes from China.

According to calculations (based on 2021), approximately 2,000 m.t./yr of magnesium could be replaced in Germany. That not only reduces the foundry industry's dependence on global raw material markets, the process offers further advantages. After being used for desulfurization, magnesium is finely distributed in a mixture as an oxide or sulfide in the slag, can no longer be economically recycled and is therefore irretrievably lost. On the other hand, lime-based desulfurization agents are significantly more environmentally friendly, less expensive, and have a lower CO_2 footprint — the production process of the raw materials contributes considerably to this.

The process has been demonstrated at the laboratory and pilot scale by ITM in cooperation with FW and OCC GmbH. FW, one of the largest foundries in the world, subsequently developed an industrial-scale system and

(Continues on p. 6)

put it into operation in parallel with normal production.

STEP DEMO

The Supercritical Transformational Electric Power (STEP) Demo pilot plant has generated electricity for the first time using supercritical carbon dioxide (sCO_2) power cycles. The $169-million, 10-MW sCO_2 facility at Southwest Research Institute (SwRI; San Antonio, Tex.; www.swri.org) is demonstrating next-generation power production technology in a project led by GTI Energy in collaboration with SwRI, GE Vernova, the U.S. Dept. of Energy/National Energy Technology Laboratory and several industry participants.

For the first time, the pilot plant's turbine achieved its full speed of 27,000 rpm at an operating temperature of 260°C and generated a small amount of power. Over the next few weeks, the STEP team will slowly ramp up the operating temperature to 500°C and generate 5 MWe of power.

After completion of this first test configuration, the STEP Demo project will enter its final phase. The pilot plant will be reconfigured to boost the power plant's efficiency and overall energy output. This modification requires the installation of new equipment, as well as a new commission and test phase that will continue into 2025 until the pilot plant is running at full power. At the end of its final phase, the pilot plant will produce 10 MWe hourly.

(Continues on p. 8)

A new reactor system for producing polymers

Traditionally, many polymerization reactions are carried out batchwise in reactor vessels, with the reaction taking place in solution, emulsion or in a melt. This procedure reaches its limits if, for example, the reaction is very exothermic or the viscosity increases considerably during the course of the reaction. To handle these situations, Entex Rust & Mitschke GmbH (Bochum, Germany; www.entex.de) has developed the planetary roller reactor (PRR), which the company introduced at Achema 2024 (Frankfurt, Germany; June 10–14).

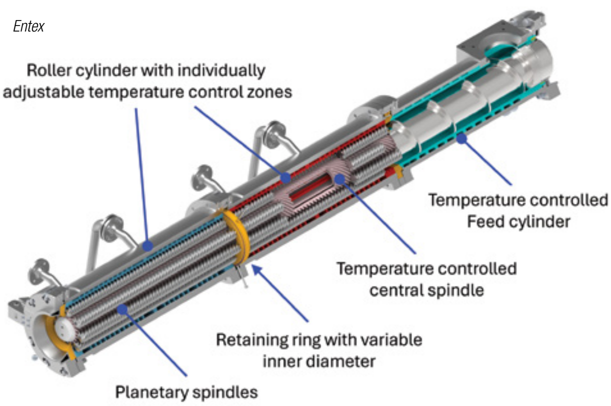
The PRR (diagram) is a multi-modular extrusion system that is mechanically adaptable while providing precise thermal process control. The system can mix, homogenize, degas and gently remove volatile components — even from highly viscous extrudates. The PRR can serve as a continuous reactor, particularly for reactions involving highly viscous thermoplastic melts.

The system is scalable from a few kilograms per hour to more than 10 ton/h, depending on the design size. The system also offers greater process safety, because the total amount of reactive components in the process are relatively low compared to a batch process. Thanks to the precise temperature and pressure profiles, the PRR is able to reproducibly deliver high product quality. Efficient degassing in the system results in lower emissions, as well as fewer volatile degradation products, compared to batch systems, the company says.

Unlike conventional single- or twin-screw extruders, the PRR can still operate without any problems even when it is only filled to around 10%. This gives the operator more flexibility when adjusting capacity.

The extruder can be continuously fed with recipe-related amounts of various solids and liquids in different process and temperature control zones, and the residence time in the individual process zones of the process section can be controlled mechanically. A chemical reaction can extend over several process zones and run through different pressure and temperature conditions, which specifically influence the course of the reaction.

Entex



Enzyme-treated rock particles are accelerating carbon sequestration

In a first-of-its-kind trial project, a CO_2-removal method known as enhanced rock weathering (ERW) is being combined with biotechnology to accelerate atmospheric CO_2 sequestration. FabricNano (London, U.K.; www.fabricnano.com) and Veolia (Paris, France; www.veolia.com) have embarked on a partnership wherein enzymes applied to rocks are being used to permanently store atmospheric CO_2 via ERW. This ERW trial, located near Bicester, U.K., involves large-particle basalt rock fines sourced from local mining operations. When spread over the ground, the rocks react with CO_2 in rainwater to permanently store it.

Currently, ERW processes are limited by mass transfer (CO_2 diffusion into water over rock surface area) and by the equilibrium rate of carbonic acid formation when CO_2 is dissolved in water, but immobilizing enzymes onto rocks promises to drastically shorten the timescale for carbon sequestration, and also enable the use of larger rock particles.

"Applying the enzyme to the surface of ultramafic silicate rocks (most commonly basalt) shifts the equilibrium from mostly CO_2 and water to mostly carbonic acid, which then reacts with the salt in the rock, such as calcium, magnesium or sodium, to neutralize the acid, thereby weathering the rock," says Grant Aarons, CEO and co-founder of FabricNano. For the ERW trials, a recombinantly expressed carbonic anhydrase enzyme has been acquired as protein powder and then reformulated to optimize immobilization to silicate rocks. Aarons emphasizes that this enzyme is commonly encountered in agricultural settings, as it is naturally released into soil by microorganisms.

"We use 1-L reactors to accelerate ERW testing in the laboratory where we can feed CO_2 at higher rates than exist in the ambient atmosphere," says Aarons. This trial is the next step in moving from the laboratory to the field. "We are planning more than ten additional trial sites with Veolia this year, where each site is 5–30 hectares in size," says Aarons.

CO_2-to-methanol conversion improved with catalyst-support ion swap . . .

Researchers at Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) and a team of interdisciplinary scientists tripled the yield of methanol in the catalytic hydrogenation reaction of carbon dioxide by introducing hydrides into the catalyst support material. The researchers say the higher yield is "due to the direct participation of surface hydrides in the reaction, and the modified electronic property of the interfacial sites" in the hydride-containing catalyst. It is the first time anion substitution has been used in this context.

The team designed a catalyst that employed copper nanoparticles supported on a perovskite (barium titanate) to convert CO_2 to methanol. Barium titanate support was chosen because it is among the few materials in which hydrogen anions (hydrides) can be incorporated to form a stable oxyhydride. Usually, hydrides are highly reactive toward air and water. In addition, the scientists hypothesized that the incorporated hydrogen anions might affect the electronic properties of the copper atom at the interface between the catalyst and support.

"A perovskite allows you to tune not only the cations almost across the periodic table, but also the anion sites," says project head Zili Wu, leader of ORNL's Surface Chemistry and Catalysis group. "You have a lot of tuning 'knobs' to understand its structure and catalytic performance."

The ORNL research team conducted a range of characterization techniques to examine the structure of the copper, the support and the interface under real-world reaction conditions to correlate structure with performance, the ORNL team explained. Boosting the performance of hydride-containing catalysts for CO_2-to-methanol conversions would enhance the portfolio of CO_2-abatement technologies.

The ORNL work has been published in a recent issue of the journal *Angewandte Chemie International Edition.*

. . . and CO_2 captured in stationary energy storage battery

Meanwhile, another Oak Ridge National Laboratory (ORNL) team created and tested two different formulations for stationary batteries that could utilize CO_2 from industrial sources while storing energy from wind turbines and solar panels. Consisting of two electrodes in a saltwater solution, the battery pulls atmospheric CO_2 into its electrochemical reaction and releases only valuable byproducts. The CO_2 batteries form carbonate byproducts that dissolve in the battery's electrolyte solution. Battery design can be tuned to remove the byproducts for use in other industrial processes, the ORNL researchers say.

In one formulation, a sodium-CO_2 battery combines gas with sodium from saltwater using an inexpensive iron-nickel catalyst. The electrodes are separated into wet and dry chambers, with a solid ion conductor between them. To make the battery work, the researchers overcame the formation of a film on the electrode surface that deactivates the battery. The team, led by ORNL scientist Rahul Amin, found that uneven pulses of charging and discharging prevented the buildup.

In a second formulation, the scientists created an aluminum-CO_2 battery that was capable of operating for more than 600 h without losing capacity, far longer than the only other aluminum-CO_2 battery that has been reported. Also, the new aluminum-CO_2 battery captures almost twice as much CO_2 as the sodium-CO_2 battery and the system can be designed to operate with both electrodes in the same liquid solution, so there is no barrier to ion movement. ORNL scientists are improving the batteries for scaleup.

Unlike conventional steam power plants, which use water as the thermal medium in power cycles, STEP uses high-temperature sCO_2 to increase efficiency by as much as 10% due to its favorable thermodynamic properties (for more details, see *Chem. Eng.* August 2020, p. 6).

BIOSURFACTANTS

At the end of May, Evonik Industries AG (Essen, Germany; www.evonik.com) inaugurated its new sustainable biosurfactant plant together with key customers in Slovakia. The triple-digit million-euro facility, which is based at Evonik Fermas, the company's site in Slovenská L'upca, Slovakia, is said to be the first worldwide to manufacture industrial-scale quantities of rhamnolipid biosurfactants. These sustainable biosurfactants are already being used in the cleaning, beauty and personal care industries, and have huge potential in many other applications, Evonik says.

Evonik has been leading the development of industrial-scale biosurfactants with its IP-protected, fermentation-based process for rhamnolipid production. Rhamnolipids are made from renewable corn feedstocks using a biotechnological process. This yields a high-performing, non-toxic, biodegradable biosurfactant. Rhamnolipids are increasingly in demand because they provide a sustainable alternative to surfactants based on fossil sources or tropical oils.

RENEWABLE BTX

Last month, BioBTX (Groningen, the Netherlands; biobtx.com) secured over €80 million to launch its first commercial-scale plant. This investment will fund the world's first renewable chemicals plant utilizing BioBTX's Integrated Cascading Catalytic Pyrolysis (ICCP) technology to produce sustainable aromatics (benzene, toluene, xylenes; BTX) from plastic waste and biomass. BioBTX aims to scale up its technology at the PETRA Circular Chemicals Plant in Delfzijl, the Netherlands. The PETRA plant will convert 20,000 ton/yr of mixed plastic waste into renewable aromatics. The demonstration plant is scheduled to go into operation by early 2027.

SUSTAINABLE ACRYLONITRILE

Last month, Trillium Renewable Chemicals (Knoxville, Tenn.; trilliumchemicals.com) announced the selection of INEOS Nitriles' (www.ineos.com) Green Lake facility in Port Lavaca, Tex. to establish the world's first demonstration plant for converting plant-based glycerol into acrylonitrile. Set to commence operations in early 2025, the so-called Falcon Project will run through early 2026.

The Trillium process begins with glycerol (byproduct of biodiesel manufacturing), which is converted to acrolein via a dehydration reaction. Next, the acrolein undergoes an ammoxidation reaction in the presence of ammonia and oxygen to generate acrylonitrile (*Chem. Eng.*, April 2022, p. 8).

BIOMATERIALS

A study, led by researchers of VTT Technical Research Center of Finland (Espoo; www.vttresearch.com) and described in a recent issue of *Advanced*

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Materials, introduces a transformative approach to significantly accelerate the development of new biomaterials. "By leveraging the power of AI [artificial intelligence] and synthetic biology, we have managed to fine-tune and dramatically speed up the design process of new protein-based materials, allowing for the rapid development of biomaterials with tailored functionalities, achieving what used to take years in just months, with the potential to further reduce this time to minutes," says Pezhman Mohammadi, VTT's senior research scientist and the head of the study. By utilizing machine learning algorithms, VTT's research team was able to efficiently sift through thousands of protein structures to pinpoint the most promising candidates for laboratory synthesis. The research team, including collaborators from VTT, the Polish Academy of Sciences, Temple University, Nanyang Technological University and Aalto University.

HEAT RECOVERY

Valmet Oyj (Espoo, Finland; www.valmet.com) will supply its DNA Automation technology to the data center heat-recovery concept developed by Fortum Oyj (Espoo, Finland; www.fortum.com) and Microsoft Corp. (Redmond, Wash.; www.microsoft.com). Valmet DNA will control water-to-water heat pumps, air-to-water heat pumps and two electric boilers at two Fortum Power and Heat Oy's heat-pump plants, which will be built in Espoo and Kirkkonummi, Finland.

The heat-pump plants will recycle excess heat from Microsoft's two planned large data center areas to Fortum's existing district heating network. The data centers will eventually provide 40% of the consumed heat in the network area. Fortum's district heat in Finland will be produced coal-free during 2024 and carbon-neutrally before 2030. ❐

A fungus converts cellulose directly into a platform chemical

Conventional bioprocesses use three separate steps to convert cellulose into products, such as bioplastics and biofuels. The consolidated bioprocess (CBP) combines all steps — cellulase production, cellulose hydrolysis and product fermentation — in a single reactor.

Using the natural abilities of the non-genetically modified fungus, *Talaromyces verruculosus*, a research team from the Leibniz Institute for Natural Product Research and Infection Biology — Hans Knöll Institute (Leibniz-HKI; Jena, Germany; www.leibniz-hki.de) has discovered a method for the efficient conversion of cellulose into enantiopure *erythro*-isocitric acid — a chiral isomer of citric acid with a large potential as a chemical building block. The study was published by the Jena team in the journal *ACS Sustainable Chemistry & Engineering*.

As natural metabolic products of most living organisms, citric acid and isocitric acid are among the most widespread acids in nature. Citric acid is produced industrially in large quantities using the mold fungus *Aspergillus niger*. With a global production of around 2.8 million ton/yr, it is one of the highest-volume biotechnological products. However, citric acid is produced from sugar and is therefore in direct competition with food production, so its use as a building block has so far been neither economical nor sustainable.

Isocitric acid is very similar to citric acid; only one hydroxyl group is positioned on a different carbon atom. This makes the molecule asymmetric, with two different diastereomers: *threo*- and *erythro*-isocitric acid. Each diastereomer has two mirror-image variants, the D- and L-forms. Citric acid and isocitric acid have almost identical properties and it can be assumed that the iso form would be just as widely applicable. The reason why this is not the case is that there has not yet been an efficient production process for pure isocitric acid, so it is currently only available as an expensive (€18,000/kg) research chemical. However, the new — now patented — production process enables sustainable and inexpensive production from plant waste and residues, such as straw, waste paper or wood residues, which could make it possible to produce isocitric acid even more cheaply than citric acid in the future.

A closed-loop hydrometallurgical process for low-carbon iron processing

Electrification will be a key factor in decarbonizing hard-to-abate sectors, but challenges arise in applications that require very high temperatures, such as steel production. The intense heat requirements for converting iron ore into metal contribute significantly to the CO_2 emissions of the steel sector. A new hydrometallurgical process that promises to remove CO_2 from this process is being scaled up in a new pilot plant operated by Electra (Boulder, Colo.; www.electra.energy). "Unlike traditional methods that rely on high temperatures near 3,000°F to melt and chemically transform ores, which emits significant amounts of CO_2, Electra's technology operates at 140°F, enabling seamless integration of intermittent renewable energy resources and making emissions-free iron possible," says Trevor Braun, Electra's senior manager of electrochemical development & testing.

Besides lower operating temperatures, one of the reasons that Electra's process is so suitable for electrification is its ability to start and stop production quickly, which promotes the use of intermittent renewable electricity when it is available.

"Electra's process can utilize a wide variety of iron ores, even already-mined feedstock, dissolving them in an acidic solution using a proprietary process. Then, we use a hydrometallurgy technique to purify the solution, where all the impurities are removed and refined into separate co-products, such as alumina and silica. After purifying the iron solution, we use electricity to deposit the iron from the solution onto reusable metal plates. The iron metal is then harvested from the steel plates and sent to the steelmaker," explains Braun. This closed-loop process regenerates consumables, such as water and acid, enabling circular clean-iron production.

Since 2020, the process has scaled up from producing 50-cm^2 iron plates in a bench-scale system to commercially relevant 1-m^2 plates. "The pilot plant will continue to evaluate iron ores from all over the world, focusing on impurity removal to produce 99% pure iron. We're currently evaluating sites throughout the U.S. for the first phase of our commercial deployment," adds Braun. ■

Business News

Plant Watch

Agilyx polystyrene depolymerization plant commissioned in Japan

June 7, 2024 — Agilyx ASA (Tigard, Ore.; www.agilyx.com) announced that its depolymerization technology was successfully demonstrated during commissioning of Toyo Styrene's 10-ton/d chemical recycling facility in Japan. The recycling plant will convert used polystyrene into a styrene monomer enabled by Agilyx depolymerization technology. The styrene monomer will then be converted back into new polystyrene products. Construction of the facility was completed in March 2024. During the subsequent commissioning phase, polystyrene was successfully depolymerized and converted to on-specification product.

Air Liquide to construct new high-purity gas plant in Idaho

June 6, 2024 — Air Liquide S.A. (Paris, France; www.airliquide.com) will build a new industrial-gas production facility in Idaho to supply semiconductor manufacturer Micron Technology, Inc. The plant will provide large volumes of high-purity industrial gases for the production of memory chips. Air Liquide will invest over $250 million in this state-of-the art production unit. The facility is expected to be operational by the end of 2025.

Borealis to establish recyclate-based polyolefins compounding line in Belgium

June 6, 2024 — Borealis AG (Vienna, Austria; www.borealisgroup.com) announced the installation of a semi-commercial demonstration recyclate-based polyolefins (rPO) compounding line in Beringen, Belgium. It is expected to be fully operational in the first half of 2025. The new line will use Borealis' proprietary technology to transform mechanically recycled post-consumer waste into rigid polypropylene (PP) and polyethylene (PE) materials.

Wacker opens new manufacturing site for mRNA active ingredients

June 4, 2024 — Wacker Chemie AG (Munich, Germany; www.wacker.com) opened a new facility at its biotech site in Halle, Germany that enables the large-scale production of active ingredients based on messenger ribonucleic acid (mRNA), such as anti-Covid mRNA vaccines. Wacker invested more than €100 million in this construction project.

BASF inaugurates second dispersions production line in Daya Bay, China

May 30, 2024 — BASF SE (Ludwigshafen, Germany; www.basf.com) announced the inauguration of its second polymer dispersions production line at the Daya Bay site in Huizhou, China. With this new production capacity, the plant will provide comprehensive support to various industries, including paints, construction, packaging and adhesives.

Mitsui Chemicals to set up mass-production facilities for CNT pellicles

May 28, 2024 — Mitsui Chemicals, Inc. (Tokyo; www.mitsuichemicals.com) will set up mass-production facilities at its Iwakuni-Ohtake site for carbon nanotube (CNT) pellicles, which are used to reduce the size and increase the production efficiency of semiconductors. The new plant is expected to be completed in late 2025, with capability to produce 5,000 sheets/yr. Mitsui's pellicle product is a dustproof photomask cover for the photolithography process used in semiconductor wafer-etching.

Toray to expand fiber production capacities in South Korea

May 28, 2024 — Toray Group (Tokyo, Japan; www.toray.com) plans to invest 500 billion won (around $360 million) in the Gumi National Industrial Complex in South Korea by 2025 to expand its production of high-performance carbon fiber, aramid fiber and other materials. This expansion will secure 5,000 metric tons per year (m.t./yr) of production capacity for fiber products at the Gumi site.

BASF to increase PA and PBT production capacities in India

May 23, 2024 — BASF India Ltd. will increase the production capacity of its polyamide (PA) and polybutylene terephthalate (PBT) compounding plants in Panoli, Gujarat and Thane, Maharashtra. The project involves a capacity increase of over 40% in Panoli and Thane, providing polyurethane for transportation, construction, footwear, appliances and furniture manufacturing. The increased capacity will be available in the second half 2025.

Mergers & Acquisitions

Occidental and BHE Renewables form JV to commercialize DLE technology

June 4, 2024 — Occidental Petroleum Corp. (Houston; www.oxy.com) and BHE Renewables, a wholly owned subsidiary of Berkshire Hathaway Energy, formed a joint venture (JV) for the demonstration and deployment of Occidental subsidiary TerraLithium's Direct Lithium Extraction (DLE) and associated technologies to extract and commercially produce high-purity lithium compounds from geothermal brine. BHE Renewables operates 10 geothermal power plants in Imperial Valley, California, which process 50,000 gal/min of lithium-rich brine. The JV has begun a project at BHE Renewables' Imperial Valley geothermal facility to demonstrate the feasibility of using the DLE technology.

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BASF sells its bioenergy enzymes business to Lallemand

June 4, 2024 — BASF sold its bioenergy enzymes business based in San Diego, Calif. to Lallemand's subsidiaries, Danstar Ferment AG and Lallemand Specialties Inc. This includes the Spartec product portfolio and related technologies in development. Lallemand will integrate the business and associated employees in its Lallemand Biofuels & Distilled Spirits (LBDS) business unit.

Wacker acquires Pennsylvania-based biotechnology firm

May 31, 2024 — Wacker Chemie has acquired the manufacturing assets and know-how of Bio Med Sciences Inc. (Allentown, Pa.) to expand its expertise and business in silicone-coated healthcare products. The acquired assets and a majority of the workforce will be part of a new entity called Wacker Silicone Manufactured Innovations LLC (WSMI).

LyondellBasell acquires 35% stake in Saudi Arabia's NATPET

May 31, 2024 — LyondellBasell Industries N.V. (LYB; Rotterdam, the Netherlands; www.lyb.com) and Alujain Corp. announced completion of the acquisition of a 35% interest in Saudi Arabia–based National Petrochemical Industrial Co. (NATPET) by LYB from Alujain. This move positions LYB to expand its core polypropylene (PP) business by gaining access to advantaged feedstocks. NATPET currently has approximately 400,000 m.t./yr of PP production capacity. Alujain and LYB are also jointly assessing the construction of new propylene via propane dehydrogenation (PDH) and PP facilities at the NATPET site, subject to a final investment decision.

ConocoPhillips to acquire Marathon Oil Corp. for $22.5 billion

May 30, 2024 — ConocoPhillips Co. (Houston; www.conocophillips.com) and Marathon Oil Corp. (Houston; www.marathonoil.com) announced that they have entered into a definitive agreement pursuant to which ConocoPhillips will acquire Marathon Oil in an all-stock transaction with an enterprise value of $22.5 billion. The transaction is subject to the approval of Marathon Oil stockholders, regulatory clearance and other customary closing conditions. The transaction is expected to close in the fourth quarter of 2024.

DuPont announces plan to separate into three companies

May 23, 2024 — DuPont (Wilmington, Del.; www.dupont.com) announced a plan to split into three distinct, publicly traded companies. Under the plan, DuPont would execute the proposed separations of its Electronics and Water businesses, with New DuPont continuing as a diversified industrial company comprised of the existing businesses within the Water & Protection segment (excluding Water Solutions), the majority of businesses within Industrial Solutions (including healthcare), and the retained businesses reported in Corporate (including adhesives). These businesses generated net sales of approximately $6.6 billion in 2023. DuPont expects to complete the separations within 18 to 24 months. ■

Mary Page Bailey

Innovative Membranes Empower Processes

New membranes enable traditional water treatment and emerging energy transition applications

While membranes and filters have provided a reliable and cost-effective solution for water desalination, purification and treatment as well as specialty process separations, innovative membrane and filtration technologies are now playing a critical role in energy transition and sustainability-based applications. Accordingly, membrane and filtration technologies are being developed to overcome common issues such as energy consumption and fouling, delivering more substantial energy savings and waste minimization to make traditional applications more economical and emerging applications possible.

"Membranes have revolutionized water treatment in many ways," says Kishor G. Nayar, director of business vertical – chemical processing industry, with Xylem/Evoqua Water Technologies (Houston; www.evoqua.com). "For example, before the advent of membranes for water treatment, removing salts and minerals from water was expensive and energy consuming. Demineralization or desalination of saltier water, such as very brackish groundwater and seawater, required thermal evaporators, resulting in high energy consumption. Today, reverse osmosis (RO) membrane-based water treatment systems have slashed energy consumption and operational costs" (Figure 1).

Xylem

FIGURE 1. Today, RO membrane-based water treatment systems, such as this one from Xylem, have slashed energy consumption and operational costs

Nayar continues: "Other membrane systems for removing suspended particles, such as ultrafiltration (UF), are replacing traditional gravity-based separation systems in both water pre-treatment systems and wastewater treatment, significantly reducing equipment footprint and increasing reliability and resilience.

"And, increasingly, membranes are being employed for critical roles in energy transition and sustainability-based applications, such as green and blue hydrogen and to reduce the water footprints of several industries," says Nayar.

Improved water treatment

"Membranes play a critical role in the water and wastewater treatment systems across industries, especially chemical plants," says Nayar. "At various stages of the process, chemical plants employ UF and other particle filtration membranes to remove suspended solids from river water; RO systems to generate demineralized water and continuous electrodeionization (CEDI) systems for polishing RO water for use as boiler make-up water.

"UF membranes are also used in membrane-based biological wastewater treatment systems, called membrane bioreactors (MBRs), to separate biosolids from treated effluent, allowing highly compact wastewater treatment systems and improved treatment efficiencies," Nayar continues. "With increases in potable water reuse applications, membranes are also used in advanced wastewater treatment applications for directly recovering drinking water-quality effluent from wastewater. Typically, such applications include MBR-RO systems with other treatment steps such as disinfection."

To enable these and other advanced water treatment technologies, membrane developers have had to overcome significant challenges, says Henia Pransky, senior vice president of membrane operations with Kovalus Separation Solutions (formerly Koch Separation Solutions; Wilmington, Mass.; www.kovalus.com). "The challenges are different in various applications, but a common challenge is meeting environmental, social and governance (ESG) goals at minimal costs," she says. "Some market segments look at the investment cost, but more and more projects consider the overall lifecycle cost of the project. To reduce lifecycle cost, the 'optimal membrane' must be energy efficient, fouling resistant and high flux, highly chemical resistant and offer a small footprint via high packing density, while providing excellent separation properties."

"Among these challenges, energy efficiency is one of the greatest considerations when weighing the benefits of different filtration technologies," says Tina Arrowood, global technology manager, growth and sustainability, with DuPont Water Solutions (Edina, Minn.; www.dupont.com). "In addition to reducing the environmental footprint of their operations, the high cost of energy means that there is also a significant economic argument for companies to adopt more energy-efficient technologies."

Accordingly, many chemical and petrochemical facilities with large wastewater streams operating in water-stressed regions are increasingly looking to reduce or reuse liquid discharge via membrane-based minimal liquid discharge (MLD). "Though there has been significant progress, a zero-liquid discharge (ZLD) solution can be prohibitively expensive in terms of capital and operating costs and, due to high levels of energy consumption, it's not the most

FIGURE 2. DuPont's FilmTec Fortilife CR200 is a high-productivity membrane that operates with a 50% reduction in cleanings, a 20% reduction in energy consumption and lower waste from cleaning chemical and element replacement compared to standard RO element types

environmentally friendly process," says Arrowood. "At a 95% water recovery rate, a membrane-based MLD approach can be operated at a fraction of the cost of a 100% ZLD system. Today's cost-effective MLD approach allows chemical processors to reduce the volume of water that needs additional dewatering via expensive thermal ZLD methods."

DuPont's recommended MLD solution blends the use of UF, RO and nanofiltration (NF) membranes for tackling tough-to-treat water challenges, including wastewater with high salt content, high suspended solids and a high level of organic pollutants. "This allows processors to improve water circularity by recovering up to 95% liquid discharge for reuse at a fraction of the cost of ZLD," she says.

Innovations in membrane technologies that overcome common challenges of membrane reliability and efficiency are enabling this type of solution. For example, DuPont's FilmTec Fortilife CR200 RO elements (Figure 2) help address the challenges of wastewater reuse with an advanced design that allows it to operate with up to 50% fewer cleanings due to fouling and a 20% reduction in energy consumption compared to standard RO element types. These benefits increase operational efficiency but also reduce waste from chemical cleaning and element replacement.

Kovalus, too, offers technologies that tackle persistent challenges. For example, its NF membrane filters and recycles caustic of up to 25% strength, while Kovalus's solvent-stable NF and UF membranes and differentiated MBR membrane products provide low energy consumption when treating industrial and municipal wastewater (Figure 3).

"The range of new developments is broad and includes new chemistries to achieve improved chemical compatibility or reduce fouling, new membrane morphologies to reduce energy consumption and selectivity, new ways of operating membrane products to reduce energy consumption or to separate constituents of different properties and more," notes Pransky.

For example, New Logic Research (Minden, Nev.; www.vsep.com) has developed a unique type of membrane filter that resonates to vibrate the membrane and create a very high shear at the membrane surface to combat fouling, scaling and plugging (Figure 4). "This has the effect of keeping the membrane from scaling or plugging," explains Greg Johnson, CEO, with New Logic Research. "Our membrane would be used where the selectivity of a membrane is desired but conventional spiral membranes cannot be used due to fouling and scaling potential, including very difficult effluent streams, such as landfill leachate or pig manure."

Optimization of membranes

Emerging applications are still defining membrane construction and the best way of optimizing membranes for each of these applications is currently evolving, says Franchessa Sayler, global technology manager, IXM, with Chemours (Wilmington, Del.; www.chemours.com). "The membranes used in these applications today are likely not the membranes that will be used in these applications tomorrow — a lot of R&D work and infrastructure development is still needed to meet the needs of emerging markets," says Sayler. "Because sustainability-based applications are still emerging, the challenge is trying to design the optimal solution for each application."

Saylor points to redox flow batteries, which are used to help manage variable power output from intermittent power sources, such as solar or wind, by storing power when production is high and discharging power to the grid when production is low, as an example of an emerging application that is now possible thanks to innovative membrane development. "Chemours's Nafion membranes are used in redox flow batteries to separate the catholyte and anolyte while allowing selective transport of ions during charging and discharging cycles," says Saylor.

Chemours' Nafion ion exchange materials, including membranes, dispersions and resins (Figure 5), play a vital role in other transformative energy industry applications, as well, including fuel cells, energy storage and water electrolyzers. "Each of these applications can leverage the unique characteristics of Nafion materials, such as their chemical and mechanical durability and electrical conductivity," adds Sayler.

For example, Chemours Nafion proton exchange membranes (PEM) find use in technologies that are critical to scaling clean hydrogen, namely water electrolyzers that convert renewable electricity into clean hydrogen energy and fuel cells that deploy hydrogen energy for use in transportation and serve as backup power for hospitals, buildings and heavy industry. "In water electrolysis, our membranes offer a way to generate clean hydrogen while generating zero emissions when powered by renewable energy, such as wind or solar, while in fuel cells, our membranes convert clean hydrogen — instantly — making fleets of fuel cell-powered transportation a reality," says Saylor.

Similarly, W.L. Gore & Associates (Putzbrunn, Germany; www.gore.com) offers Gore-Select, PEM and Membrane Electrode Assemblies

FIGURE 3. Kovalus's solvent-stable NF and UF membranes and differentiated MBR membrane products provide low energy consumption when treating industrial wastewater. Shown here is a large-scale Puron MBR System for wastewater treatment

FIGURE 4. New Logic Research has developed a unique type of membrane filter that resonates to vibrate the membrane and create a very high shear at the membrane surface to combat fouling, scaling and plugging

(MEAs) to enable large-scale hydrogen fuel cell commercialization throughout major industrial market sectors, from stationary power generation to global long-haul transportation, says Ed R. Harrington, strategic account manager. Within the fuel cell, the PEM separates hydrogen and oxygen and transports protons from the anode to the cathode. These functions make the fuel cell PEM one of the most important determinants of fuel cell stack performance and service life.

Kovalus's Pranksy adds that membrane innovation is necessary to support a multitude of other emerging green energy applications: "Whether membranes serve in the extraction process of lithium for EV batteries as pretreatment to the direct lithium-extraction (DLE) process, high brine concentration RO, biofuel processing to remove contaminants and concentrate byproducts of the process or other separation challenges, the innovation in the market driving sustainability creates a landscape of innovation in the membrane field."

Pranksy continues to say that one of the most significant advancements in supporting sustainability-based applications is the introduction of industrial-scale high-brine RO technologies. "Various technologies have demonstrated successful operation reaching 200–250 g/L salt concentrations," she says. "These newer technologies are used in lithium extraction, as well as other new applications and are also used in traditional desalination systems to increase system recovery and reduce concentrate disposal volumes."

Along these lines, DuPont offers its FilmTec LiNE-XD nanofiltration elements to aid in high lithium recovery from new sources, such as geothermal brines, salt lakes and surface and sub-surface clay. "Lithium mass recovery can be optimized with enhanced purity as non-essential metal ions are filtered out," says Arrowood. "Importantly, lower energy consumption and up to 30% in energy savings can be realized with these solutions."

Membrane development also enables more cost-effective green and blue hydrogen production processes. "Traditionally hydrogen is produced from natural gas through either steam-methane reforming (SMR) or auto-thermal reforming (ATR) processes, consuming 6% of the global natural gas production to synthesize hydrogen gas for petrochemical, ammonia, methanol and steel production," explains Xylem's Nayar. "Governments worldwide have incentivized producing low-carbon hydrogen to help decarbonize heavy industries."

In green hydrogen, the hydrogen is produced by using low-carbon electricity to power electrolyzers that split water, whereas in blue hydrogen, carbon dioxide produced in the SMR and ATR process is captured and sequestered. "Both need membrane-based water treatment. For green hydrogen, ultrapure water is required as the feed water to the electrolyzers. For blue hydrogen, demineralized water is required as boiler make-up water," notes Nayar. "Typically, every kilogram of hydrogen produced can exert a water demand of 5 to 20 gallons for blue hydrogen and 16 to 30 gallons for green hydrogen. Membranes are sometime required in wastewater treatment for blue-hydrogen projects when discharge limits are very stringent."

FIGURE 5. Chemours's Nafion ion exchange materials, including membranes, dispersions and resins, play a vital role in transformative energy industry applications including fuel cells, energy storage and water electrolyzers

DuPont's Arrowood says the company is supporting the green hydrogen revolution with ion exchange resins designed for water electrolyzers. "While there are various types of electrolyzers, they all rely on high-purity water as the feedstock to produce hydrogen. DuPont AmberLite P2X 110 ion exchange resins are designed to endure the thermal and chemical challenges present in an electrolyzer," she says. "This solution can offer durable and reliable water quality that helps prevent contaminant build up in the electrolyzer loop."

Evonik Industries AG (Essen, Germany; www.evonik.com) has also developed advanced membrane technology to support the production of green hydrogen. "Our Duraion product is an anion-exchange membrane (AEM) that features top-class stability and ion conductivity when subjected to harsh alkaline conditions, which are needed for AEM electrolysis," says Vincent Lee, market communications, with Evonik.

Evonik also specializes in membrane technology solutions for biofuels processing. The company's Puramem membrane products are designed for organic solvent nanofiltration (OSN) applications, which contribute to winterizing and upgrading biodiesel. "These membranes feature efficient separation at near-ambient temperatures without the need for a phase change of the liquid feed," says Lee.

The company's High-Performance Polymers business also provides a range of membranes for highly efficient gas separation. "Our Sepuran Green product line, for example, features high carbon-dioxide and methane selectivity, which makes the product ideally suited for biogas upgrading," explains Lee.

"While membranes and filtration provide safe, reliable and economical treatment of water and wastewater, they also provide process solutions for the high-growth lithium extraction and green hydrogen sectors. Advanced membranes for industry and energy use provide options to achieve a more water- and energy-resilient future for a growing economy," says DuPont's Arrowood. ■

Joy LePree

Focus on Sensors

TWTG Group

Hilscher

Innovative Sensor Technology IST

Leuze Electronic

Sensor-fusion technology boosts predictive maintenance

This company introduced new sensor-fusion technology for compatible sensors within its NEON product range (photo). Sensor-fusion technology combines data from multiple sources to deliver a more comprehensive and accurate overview of industrial systems. This technology, particularly the NEON EventSync and TimeSync functionality, promises substantial advances in intelligent predictive maintenance and operational management. The introduction of TimeSync ensures precise time alignment across sensor networks, which is crucial for data accuracy and real-time analysis. Complementing this, EventSync delivers intelligent, event-driven data collection from multiple sources. When viewed via the company's SolidRed IIoT platform, these data enable engineers to have a more profound understanding of the relationship between sensors, equipment and data. — *TWTG Group B.V., Rotterdam, the Netherlands*
www.twtg.io

New masters for instant monitoring of sensor data

Two new Edge IO-Link masters have been launched to help users modernize their machines and plants through instant IO-Link machine monitoring. The new devices can connect directly to Ethernet-based IT infrastructures without the need to interface with existing communication networks and their control systems. Based on a central platform, sensorEDGE allows you to remotely monitor up to eight IO-Link sensors. Requiring only a power supply and an internet connection, the sensorEDGE box transmits data into the cloud at one-second intervals for direct analysis. Featuring two container engines and optional cloud support, sensorEDGE Field (photo) connects up to eight local IO-Link sensors and includes an open computing platform for your own software with centralized management. SensorEDGE devices combine computing power and IO-Link master technology in one IP67-rated housing. — *Hilscher Gesellschaft für Systemautomation mbH, Hattersheim, Germany*
www.hilscher.com

A new moisture-in-oil sensor for continuous monitoring

To operate a gearbox, a transformer or an industrial plant safely and stably over a long period of time, it is often necessary to monitor the condition of the lubricants with the support of sensor technology. For such monitoring functions, this company has developed the new Moisture-in-Oil sensor (photo). This is a compact, digital humidity and temperature module (RH/T) that measures the relative degree of saturation of water (in %RH) in oils and fuels. The sensor is delivered temperature compensated and calibrated, and with a test board with analog (0–10 V) outputs. — *Innovative Sensor Technology IST AG, Ebnat-Kappel, Switzerland*
www.ist-ag.com

These sensors are easy and flexible to use

Thanks to an adjustable sound cone and small dead zone, the new ultrasonic sensors of the 420B and 412B Series can be used for many different applications. The new ultrasonic sensors are available as switching (HTU) or measuring (DMU) sensors. The sound cone can be set via an IO-Link interface to narrow, medium or wide ranges, and thus adapted to the respective application. They are able to detect reliably in situations where optical sensors are pushed to their limits. They also detect glossy, reflective, very dark or transparent surfaces, as well as liquids without problem. HTU420B ultrasonic sensors are suitable for challenging detection tasks. For example, two fill levels can be detected or two positions can be monitored simultaneously. Moreover, to measure distances, system operators can make use of the DMU420B and DMU412B ultrasonic distance sensors. — *Leuze Electronic, Inc., Duluth, Ga.*
www.leuze.com

This hygienic level sensor is FDA compliant

The capacitive sensor KA1590 (photo) from the 26 Series now has IO Link Technology. This IO Link sensor can detect products with a dielectric constant as low as 1.1. The sensor comes with normally open contact and normally closed contact. On and off delay-timing functions are programmable for the application requirements. The sensor operates on 10–35 V d.c., the housing is IP67 sealed for cleaning in place and installation is quick with tri-clamp mounting. The polytetrafluoroethylene (PTFE) housing is FDA 21 CFR 177.1550 compliant for use in food and pharmaceutical applications. The sensor has a temperature rating up to 100°C. Applications include level control for batching of paste-type products, liquids and bulk solids and powders used in food and pharmaceutical manufacturing. — *Rechner Electronics Ind. Inc., Sanborn, N.Y.*
www.rechner.com

These position sensors can tolerate temperature spikes

This company offers several linear variable differential transformers (LVDTs) with an extended 400°F temperature range for use in applications where temperature spikes are possible. The transducers ensure reliable position measurement in applications with fluctuating temperatures where standard-temperature sensors can fail due to deteriorating insulation and intermittent connections. For example, standard temperature position sensors used on steam valves may unexpectedly fail when the valve is in motion due to temperature spikes caused by steam leaks. Failures also can result from hot-gas outbursts or temporary exposure to opened furnace doors. Replacing these standard units with a higher temperature LVDT stops failures, eliminates bad readouts and reduces downtime associated with maintenance. — *NewTek Sensor Solutions, Pennsauken, N.J.*
www.newteksensors.com

Magnetic field and temperature sensor with IO-Link

The CMMT three-axis magnetic field/temperature sensor with IO-Link (photo) is this company's third sensor type developed for easy-to-use and retrofittable condition-monitoring applications. It complements the existing range, consisting of the CMVT vibration and temperature sensor and the CMTH for humidity and temperature measurements. The combined measurement of magnetic field and temperature with the CMMT enables simple detection of faults on motors or in processes with magnetic components. The new sensor also opens up applications that were previously impossible, such as the contactless detection of the rotation and movement of metal objects without visual contact. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

A pressure sensor for hygienic applications

Using a dry measuring system, the BC4200 pressure gage (photo) has a flush-mounted diaphragm and all wetted parts made of 1.4435 (316L) stainless steel. The gage can be integrated into production systems by numerous EHEDG-certified process connections for hygienic requirements, such as tapered spigots with grooved union nut, clamp connections or a Varivent connection. The BC4200 series is available in various hygienic versions with different surface roughness. The BC4200 has as IP 65 degree of protection and is suitable for cleaning in place (CIP) and steam in place (SIP). — *Labom Mess- und Regeltechnik GmbH, Hude, Germany*
www.labom.com

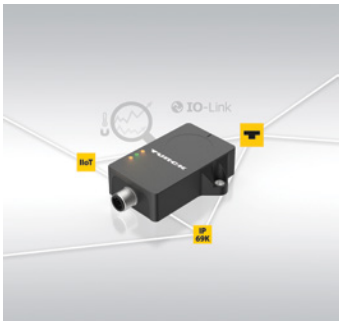
Monitor indoor air quality with this sensing module

The S88 (photo) is an accurate, compact and maintenance-free CO_2-sensing module for indoor air-quality monitoring and building automation control across a variety of environments. The S88 uses non-dispersive infrared (NDIR) technology for CO_2 detection and features the company's proprietary Automatic Baseline Correction (ABC), an algorithm that constantly tracks measurement deviations, enhancing long-term accuracy and reliability without the need for third-party interaction with the sensor. The S88 has high precision across a wide measurement range from 400 to 10,000 parts per million (ppm). — *Senseair AB, Delsbo, Sweden*
https://senseair.com ■

Gerald Ondrey

Rechner Electronics Ind.

NewTek Sensor Solutions



Hans Turck

Labom Mess- und Regeltechnik

Senseair

Facts At Your Fingertips

Hydrogen Production Methods and End-use Markets

Department Editor: Scott Jenkins

Current hydrogen demand is dominated by petroleum refining and fertilizer production, and is supplied largely by fossil-fuel-based steam-methane reforming (SMR). Increasingly, however, demand for hydrogen will come from the energy transition, and will be supplied by a more diverse range of production schemes. This one-page reference provides an overview of the traditional and emerging uses of hydrogen, as well as the current and emerging methods of production.

TABLE 1. HYDROGEN PRODUCTION PROCESSES BY "COLOR"

Hydrogen "color"	Raw material	Process	Energy source	Emissions and economics notes
Black H_2	Black coal (bituminous coal)	Gasification	Fossil fuel	Largest carbon footprint of any production method
Brown H_2	Brown coal (lignite)	Gasification	Fossil fuel	Some analyses have included biomass gasification in this category
Gray H_2	Natural gas / methane	Steam reforming	Fossil fuel	Most common and least expensive method at present (~$1/kg). Smaller carbon footprint than black or brown H_2, but still generates significant CO_2
Blue H_2	Natural gas/methane	Steam reforming	Fossil fuels	SMR is coupled with CCUS technologies to capture CO_2 emissions
Turquoise H_2	Methane	Pyrolysis	Fossil fuels	Byproduct is solid carbon (carbon black or other forms), but no CO_2 generated by the process
Yellow H_2	Water	Electrolysis	Mixed-origin grid energy	Carbon footprint can vary depending on mix of renewable and fossil energy sources
Pink H_2	Water	Electrolysis	Nuclear energy	Zero CO_2 emissions, except those used for extraction of nuclear fuel
Green H_2	Water	Electrolysis	Renewable energy (wind, solar, hydroelectric, geothermal, tidal, etc.)	Currently more expensive than blue and turquoise H_2. Several electrolyzer types are available
White H_2	Naturally occurring H_2 in underground deposits	Mining/extraction	Geologic drilling and extraction	Theoretically carbon-free, but depends on extraction techniques. Has potential to be lower cost than gray H_2
Gold H_2	H_2 produced by microbes fermenting materials in depleted oil wells	Biological fermentation	Subsurface biomanufacturing	Could make use of stranded assets in the oil and gas industry

Traditional H_2 markets

Currently, hydrogen demand is 94 million metric tons, and is concentrated in a few industrial applications, including the manufacture of transportation fuels, fertilizer production and chemical manufacturing. These are sources of most hydrogen demand today.

Petroleum refining. The greatest current demand for hydrogen is from hydrocracking and hydrotreating processes at petroleum refineries. Hydrocracking catalytically breaks C-C bonds and hydrogenates to convert heavy oil fractions to lower-molecular-weight hydrocarbons for fuels, such as diesel. Hydrotreating removes heteroatoms, such as sulfur, from hydrocarbon molecules.

Ammonia manufacturing. A significant amount of hydrogen is used to make ammonia for synthetic fertilizers and other uses via the Haber-Bosch process. Using atmospheric nitrogen from air-separation units, the Haber-Bosch process combines hydrogen with N_2 over a finely dispersed iron catalyst, accompanied by promoters.

Chemical production. Hydrogen is a critical component of many important industrial chemicals, such as methanol, hydrochloric acid, hydrogen peroxide, cyclochexane and oxo-alcohols. Hydrogen is also used in making some vitamins and pharmaceuticals.

Hydrogenation of oils. In food production, hydrogen is used for hydrogenate oils to prevent oxidation and to raise the smoke point of cooking oils, for example, partially hydrogenated vegetable oil.

Metals. Hydrogen is mixed with inert gases to generate a reducing atmosphere for some applications in the metallurgical industry, such as heat-treating of steel and welding.

Emerging H_2 end-use markets

Emerging demand for hydrogen in a number of areas is nascent, but poised to grow rapidly over the next 10 to 15 years.

Power generation. Hydrogen could be used to blend with natural gas for commercial and residential heating, and could be used to generate electricity in the power sector.

Industrial heating. Hydrogen can replace natural gas or other fuels to fire industrial burners and heat boilers to provide low-carbon heat for industrial processes, and act as a reducing agent for the steel industry.

Renewable energy storage (Power-to-X). Hydrogen can be made using surplus renewable energy as a flexible offtake and storage medium to secure and balance renewable power supply.

Transportation. Hydrogen can be used as a zero-carbon transportation fuel for road vehicles, aviation and maritime applications, including in fuel cells, or for making synthetic, low-carbon fuels.

Rocket fuel. In liquid form, hydrogen can be a powerful propellant for the space industry.

H_2 production methods

Hydrogen production processes are categorized by H_2 "colors," depending on the initial molecule being broken down, the energy source used to take hydrogen from it, and the byproducts of the chemical reaction. At present, most hydrogen produced is derived from fossil fuels (mostly natural gas, and some coal).

Production of low-carbon hydrogen is expected to grow rapidly in coming years. Table 1 outlines the different production schemes. ■

References

1. Gulli, C. Heid, B. and others, Global Energy Perspective 2023, McKinsey & Co., 2024. mckinsey.com.
2. U.S. Energy Information Administration, Energy Explained, www.eia.gov, accessed June 2024.
3. Moniz, E. and others, Hydrogen Market Formation: An Evaluation Framework, EFI Foundation, www.efifoundation.org, 2024.

New Products

V-cone blenders for gentle and effective mixing

The V-Cone Blenders utilize diffusion as the main mechanism for mixing. As the V-shaped vessel rotates on its horizontal axis, batch materials cascade down, distributing particles over a freshly exposed surface. With operating speeds of 5 to 25 rpm, this line of tumble blenders can easily mix dry solid blends (including high-density powders), low-viscosity slurries and friable materials, as well as formulations containing trace components or ingredients that are dissimilar in size, shape and density. The purpose-built Model VCB-20 (photo) is fully customized with two pneumatic cylinders affixed to the V-Cone body to disconnect and connect fiber drums for charging and discharging. The blender's dust-tight butterfly valve is operated by optional pneumatic control. To reduce the size of agglomerates, a high-speed intensifier bar is installed along the mixer's axis of rotation. Nozzles can also be attached to this intensifier bar for continuous liquid additions during the mixing process. — *Charles Ross & Son Company, Hauppauge, N.Y.*
www.mixers.com

Acoustic damping for production facilities

Basotect thermoset melamine resin foam (photo) offers outstanding acoustic properties. Because of its fine, open-cell foam structure, it can achieve sound-absorption values in the mid- and high-frequency ranges. Moreover, sound absorbers made from Basotect reduce the echo caused by reverberation on sound-reflecting surfaces. This makes conversations easier to understand in busy spaces, as well as being an effective way to reduce noise peaks in industrial settings. The lightweight Basotect absorbers are a simple way to retrofit workplaces with high noise exposure to enhance acoustics. — *BASF SE, Ludwigshafen, Germany*
www.basf.com

Motorized actuator and shutoff valve for combustion systems

The ASCO Series 148/149 safety valve and motorized actuator (photo) is designed for industrial fuel-oil burner recirculation and safety shutoff applications. The new device prevents overpressure, leaks and system malfunctions that can lead to health and safety incidents, with one configuration suited to a wide range of combustion-system applications. The combination is a compact two- and three-way system with a motorized actuator that achieves rapid, reliable fuel-line shutoff from an open to closed position in less than one second. It is engineered for robust and reliable operation in harsh outdoor environments, supporting an operating range from –40 to 66°C. — *Emerson, St. Louis, Mo.*
www.emerson.com

Custom powder containers streamline material transfer

These new powder containers (photo) feature a custom design that streamlines material transfer in a personal-care-product manufacturing process. Developed for a major private-label manufacturer, the powder containers set FDA-compliant, polyethylene bulk containers within durable, steel frames in a configuration that fits neatly into an existing processing line. Sporting designed-in fork tubes and iris-valve discharges, the custom design permits the containers to be safely and easily moved from the manufacturing line to the filling line for packaging, then quickly cleaned and returned for service at the mixer discharge upstream. — *Automated Flexible Conveyor, Inc., Clifton, N.J.*
www.afcspiralfeeder.com

Portable compressors that are easy to transport

Powerful, lightweight, quiet, versatile and easy to transport: these are the key features of the smallest models in the e-power portable compressor range, the Mobilair M10E and M13E (photo). Together with the Purpac F16 support frame, which includes a compressed air aftercooler and filter combination for the 1-m^3 class, users can even take advantage of oil-free compressed air. With an air-delivery volume of 1.2 m^3/min at 7 bars, the Mobilair M13E portable compressor is able to power pneumatic hammers, saws, sewer robots or even impact moles. The

Charles Ross & Son Company

BASF

Emerson

Automated Flexible Conveyor,

Kaeser Kompressoren

Mobilair M13 is also available in 10-, 12- and 13-bars pressure variants. Featuring a 7.5-kW motor, the manually-towable M13E rotary-screw compressor simply plugs into a 400-V CEE socket with a 32-A pre-fuse. — *Kaeser Kompressoren SE, Cobourg, Germany*
www.kaeser.com

Fluid Components International

Switches for precise measurement of gas/liquid flow

The FLT93 flow switch Series (photo) is suitable for flow detection of liquids or gases. FLT93 is a dual-function instrument capable of monitoring and alarming on both flow and temperature in a single device. FLT93 flow switches can be specified in either insertion or inline styles for installation in pipe or tube diameters from 0.25 in. and larger. In sensitive processes that require chemical and other additive injection flow in small line sizes, the FLT93L can detect liquid flowrates as low as 0.015 mL/s and gas flowrates down to 0.6 mL/s. Models FLT93S and FLT93F are insertion types and are designed for use with liquids and gases in larger-diameter pipe sizes. For sanitary processes, the Model FLT93C provides 20Ra electro-polished 316L stainless-steel wetted parts and tri-clamp sanitary flanges to meet the requirements in the food, beverage and pharmaceutical industries. — *Fluid Components International LLC, San Marcos, Calif.*
www.fluidcomponents.com

ACME Cryogenics, part of OPW Clean Energy Solutions

This valve line now has larger sizes

This company has introduced new 6- and 8-in. valve sizes for its Model CV valve product line (photo). The new valves are available in actuated and manual versions with both featuring a Class 150 pressure rating. Additionally, the company is working on creating a bellows-sealed option that will be able to handle pressures up to 550 psi, which will make them an optimal choice for hydrogen-handling applications, as well as 10-in. and larger bore sizes. Besides hydrogen-handling applications, the valves are also compatible for use in applications that require the use of a vacuum-jacketed valve and piping system. All Model CV valves are compliant with ASME B31.3 and CSA B51 regulations. — *ACME Cryogenics, part of OPW Clean Energy Solutions, Hamilton, Ohio*
www.opwglobal.com

Indco

Air mixers handle a diverse range of materials

These air mixers (photo) are designed for maximum efficiency and ease of use in diverse mixing applications. Compatible with a range of mixing blades, these air-powered devices are intrinsically safe for handling of volatile and flammable materials when electric mixers are not suitable. The MAC-150 mixer package (photo) features a 0.75-hp powerhead and a 21-in. long shaft with 5-in. integral paddle, which makes it suitable for mixing paint, resins, chemicals, ink, adhesives, block fillers and more. The rugged and dependable AM149 powerhead includes a single-handle option for ease of use and movement. The 0.75-hp air motor provides maximum agitation when supplied with 30 ft^3/min of air at 100 psi. An airflow valve allows speed control from 300 to 3,000 rpm. — *Indco, New Albany, Ind.*
www.indco.com

Xchanger

Using ambient air to cool a product tank

LC-Series heat exchangers are designed for cooling liquids or high-pressure air with ambient air. Common applications include cooling water used in fracking processes, cooling glycol or water as a cleaner alternative to smaller cooling towers, cooling compressed air and condensing chemicals from high-pressure gas mixtures. Features include a TEFC 230/460 V a.c., three-phase motor, a heavy-duty cooling fan, and OSHA-approved fan guard. The LC-60-1 heat exchanger (photo), for example, will use 45°C ambient air to cool Dowtherm T heat-transfer fluid from 120°C to 70°C. The Dowtherm T will be used to cool a Meso-lactide product tank. The core has carbon-steel tubes, fins and casing. It has an ASME code stamp on the tube side. — *Xchanger, Hopkins, Minn.*
www.xchanger.com ■

Gerald Ondrey

Which Air-Pollution Control Equipment Is Best for Your Needs?

Selecting the proper air-pollution control equipment for your process means focusing on the removal of specific pollutants while also ensuring that production goals are met

Robert Bobeck
LDX Solutions

IN BRIEF

ACID-GAS CONTROL (SOx, HCl, HF)

MERCURY, HEAVY METALS AND MORE

NOx CONTROL

PARTICULATE MATTER COLLECTION

VOCS AND HAPS

Air-pollution control (APC) equipment is used to prevent pollutants from being released into the atmosphere and is required for regulatory compliance. However, there are many APC options depending on the specific needs of an organization. Proper maintenance and operation of an APC system are crucial and will impact upstream equipment efficiency, production output and compliance. This article focuses on providing an overview of APC systems, explains their basic operating principles and describes the application for each.

There are a number of factors to consider when choosing APC equipment. The best equipment for you must meet your exhaust-emission needs, which depends on the process gas to be treated. The selection of equipment typically involves evaluation of other factors, including initial costs, longterm costs, maintenance and longevity. Understanding which factors are most important to you when meeting your APC needs can help guide the decision-making process.

The APC equipment best suited for your site depends on the pollutants to be mitigated. Here, those pollutants are categorized into the following groups, which are described in further detail throughout the article:

- Acid gas
- Mercury and heavy metals
- Dioxins and furans
- Oxides of nitrogen (NOx)
- Particulate matter (PM)
- Volatile organic compounds (VOCs)
- Hazardous air pollutants (HAPs)

Acid-gas control (SOx, HCl, HF)

Choosing the right acid-gas control equipment can have a significant impact on operation cost and is crucial to a plant's operating efficiency. Acid-gas control equipment can target a number of pollutants, including sulfur oxides (SOx), hydrochloric acid (HCl), and hydrofluoric acid (HF). The best equip-

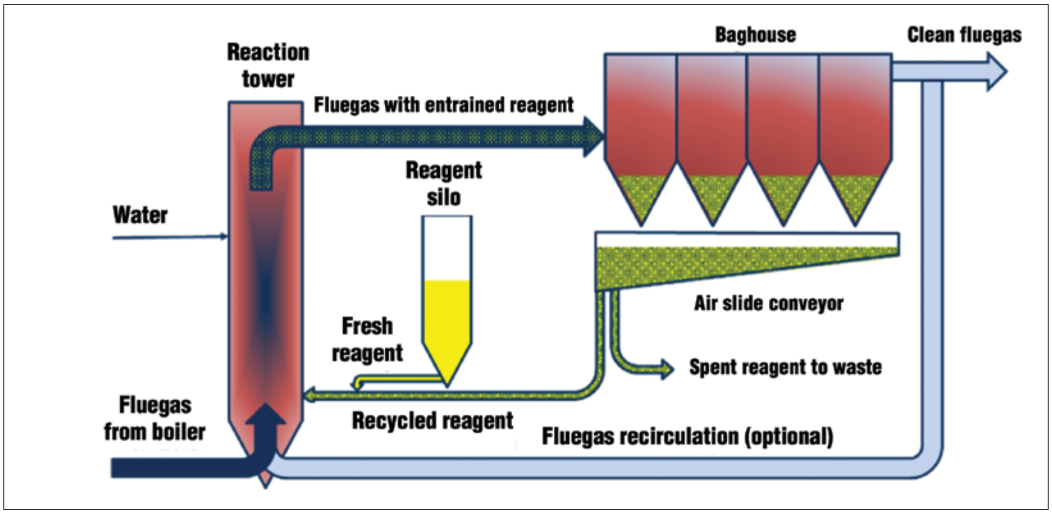


FIGURE 1. A circulating dry scrubber can serve as a multi-pollutant removal system, utilizing hydrated lime as the reagent

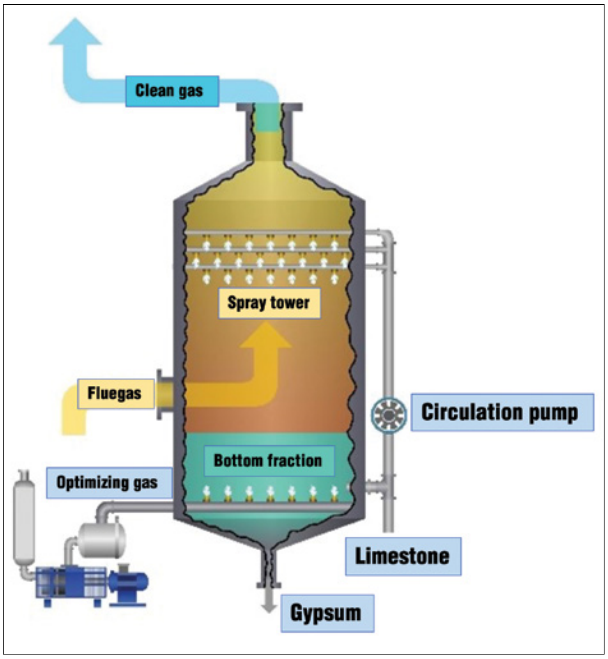


FIGURE 2. There are a number of wet-scrubber configurations that can be customized to suit specific process needs

ment will target the necessary pollutants, meet efficiency needs, require the least maintenance and, if necessary, easily integrate with existing equipment.

Circulating dry scrubbers. While focusing on acid gas, a circulating dry scrubber really is a multi-pollutant removal system. It includes a reaction tower, reagent storage silo, waste silo, baghouse, recycle-air slide conveyors and fluegas recirculation line. It typically utilizes hydrated lime ($Ca(OH)_2$) as the reagent.

The process begins when the gas enters the reaction tower and goes through a fluidized reagent (Figure 1). The reaction converts the acid into particulate matter that is transported by the gas stream to the baghouse, where it is separated from the gas stream. The collected "dust" is recycled and reintroduced into the reaction tower to optimize reagent efficiency. Fresh reagent flow is continuously adjusted to meet the emission output setpoint. Waste product is removed from the baghouse for disposal to balance the amount of reagent circulating in the system.

There are a number of advantages of the circulating dry scrubber. It can provide 99% or higher SO_2 removal efficiency. It removes SO_3, HCl, HF, Pb, dioxins, furans and Hg. Under the right conditions, it can offer up to 60% NOx removal, so if only 50% reduction is required, additional equipment may not be necessary.

The circulating dry scrubber's high recycle rate allows for low consumption of new reagent. Keep in mind that if you do not need to run at 99% SO_2 removal to meet requirements, then the amount of reagent that is needed will be accordingly lower. The circulating dry scrubber has a lower power consumption than typical wet scrubbers and has no wastewater stream. Compared to other technologies, it tends to require less maintenance and has very few moving parts. It also does not utilize a slurry, so there are no related slurry-handling issues.

Wet scrubbers. Wet scrubbers (Figure 2) are available in a number of designs. As the name indicates, the wet scrubber utilizes liquid to perform the scrubbing function. The liquid can be water or another type of aqueous solution. How the wet scrubber works will depend on the type of wet scrubber and the type of contaminant being removed.

Wet scrubber types include the following: open-spray tower; packed-bed scrubber; and Venturi scrubber. The open-spray tower involves a chemical interaction between the scrubbing liquid droplet (mostly caustic solution or lime slurry) with the pollutant. A packed-bed scrubber focuses on providing packing for increased surface area for the liquid (water, aqueous solution, caustic and so on) to contact the gases. It cannot handle a high dust load. The Venturi scrubber focuses on particulate-matter capture via high-velocity droplet atomization. Caustic can be added for acid reduction. The Venturi scrubber is discussed in more detail in the section on particulate-matter collection.

Wet scrubbers can effectively remove an assortment of contaminants from process gas streams. The typical wet scrubber is dedicated to acid-gas control, including SO_2 and HCl. In addition to acid gases, wet scrubbers may also remove particulate matter and certain organic gases.

A benefit of a wet scrubber is that it can remove both particulate matter and gases simultaneously. Wet scrubbers also tend to take up less space. However, as mentioned in the previous section, wet scrubbers have a higher power consumption than circulating dry scrubbers and generate wastewater or other waste liquid streams.

Dry-sorbent injection (DSI). DSI systems can reduce SOx, HCl, HF and more in two basic steps. First, a dry sorbent is injected into the fluegas, where it reacts with the acid gases. The compound created from neutralization is a particle. Second, a particulate-matter control device collects the unused and converted reagent, as well as particulate matter in the gas stream downstream of the dry sorbent injection system.

DSI systems (Figure 3) have

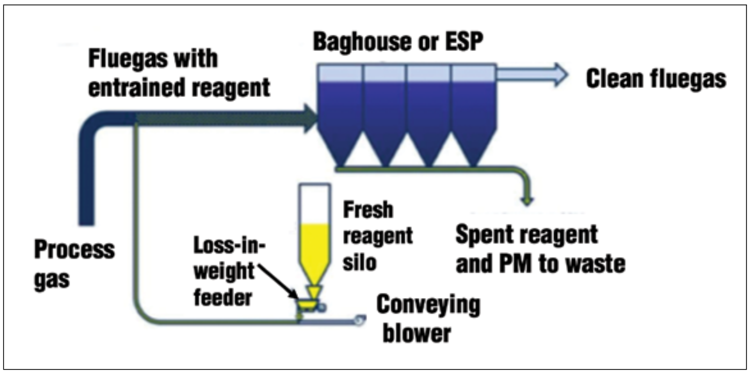


FIGURE 3. Dry-sorbent injection systems are more compact than typical scrubbing units and can easily integrate into existing plant footprints

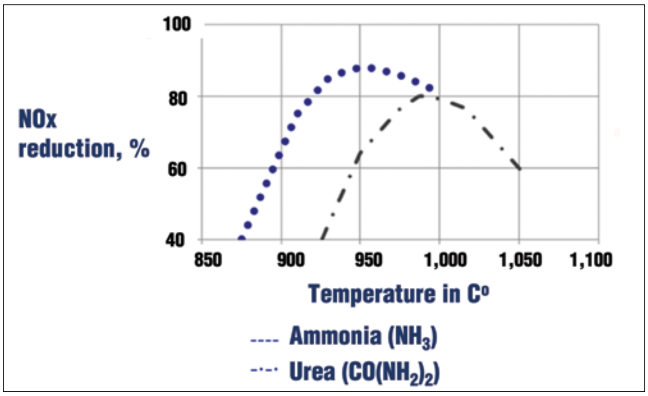


FIGURE 4. High temperatures are essential for selective non-catalytic reduction systems to work effectively

a smaller footprint than the circulating dry scrubber and wet scrubber and easily integrate with an existing baghouse or electrostatic precipitator (ESP). The systems also tend to have much lower capital costs. However, the systems tend to require a higher reagent usage, which may result in higher operating costs when compared with other systems. Dry-sorbent injection systems can be an option in smaller plants where the installation of other scrubber types would not be cost effective.

Mercury, heavy metals and more

For pollutants such as dioxins, furans and mercury and other heavy metals, it is essential to ensure system efficiency, cost effectiveness and safety — for this purpose, activated-carbon systems are usually an effective APC choice.

Activated-carbon injection (ACI). ACI and DSI systems are actually very similar systems, except that the DSI system injects an alkaline reagent (hydrated lime, sodium bicarbonate or trona) and the ACI system injects powdered activated carbon (an absorbent). Note that activated carbon is not actually a reagent. It is very porous and does not chemically react like a lime-based reagent.

ACI is utilized for absorbing emissions from fluegases. In an ACI system, the activated carbon is pneumatically injected from a storage silo into the fluegas ductwork. The activated carbon then adsorbs mercury from the fluegas and is collected with the process gas' dust in the plant's particle-collection device. ACI may remove some hydrocarbons depending on the type and process-gas conditions.

FIGURE 5. A fabric filter or baghouse dust collector can remove extremely high quantities of particulate matter from a gas stream

The efficiency of the activated-carbon injection system depends on the gas conditions and heavily depends on the temperature. An ACI system is capable of mitigating 99% of the mercury. It is an effective and cost-efficient method of reducing mercury and heavy metals from most boilers. An ACI system can be utilized in a variety of industries, including cement, coal-fired power and biomass or biofuels. It is possible for a system to operate for extended periods of time with little maintenance.

NOx control

NOx — one of the most heavily regulated pollutants from industry — is typically controlled using reduction-based APC technologies.

Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). Selective catalytic reduction systems generally use ammonia or urea as a reducing agent with a catalyst. The catalyst allows for the NOx to be removed at a lower gas-stream temperature. The SCR system will include an injection system for the reagent and a catalyst. The injection system can easily be added to an existing system, but the catalyst requires more space and a tie-in with the existing ducting system. The SCR system is temperature dependent, but not as highly temperature dependent as SNCR. It also needs regular maintenance to ensure proper performance.

As the name indicates, unlike selective catalytic reduc-

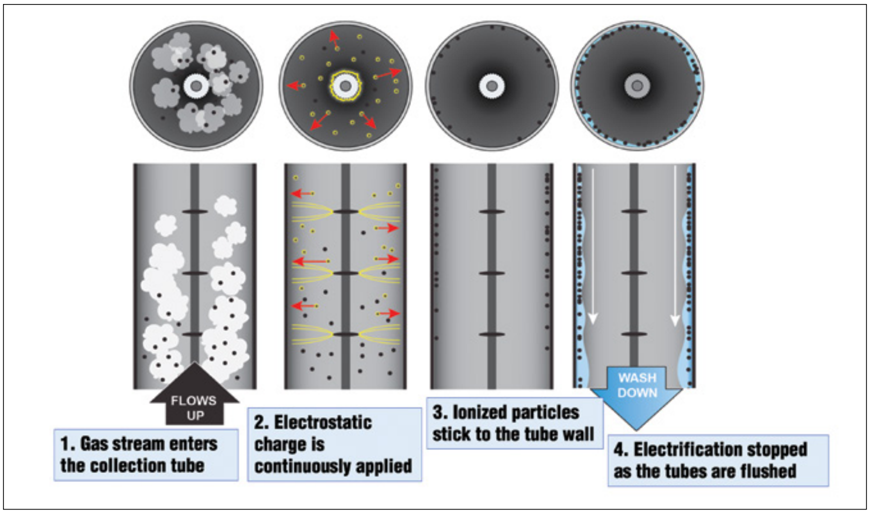


FIGURE 6. A wet electrostatic precipitator uses an electric charge to mitigate particulate-matter content in exhaust gas

tion, selective non-catalytic reduction does not use a catalyst. SNCR systems are easier to install in an existing system, and while they do not require a catalyst, they are very temperature sensitive.

The SNCR can be an ammonia or urea injection system. For the reaction to take place, the temperature must be extremely high (Figure 4). Liquid ammonia is injected into the NOx-containing process gas and the ammonia removes the oxygen from the NOx and makes it nitrogen and water vapor. There are many different ways of performing the ammonia injection:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$2NO + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

With both selective catalytic and non-catalytic reduction, there will also be different safety regulations that will come into play depending on the ammonia type and concentration. This will include regulations regarding the handling of ammonia, as well as requirements for the containment area in case of an ammonia leak.

SCR and SNCR are both post-combustion technologies and commonly used NOx-reduction technologies. The SCR provides higher NOx-removal efficiencies, typically providing well over 80% NOx reduction. This is accomplished within a lower temperature range than is required in SNCR systems. U.S. Environmental Protection Agency (EPA) regulations support or require NOx-control installations to achieve the lowest emissions level possible.

Particulate matter collection

Particulate matter includes solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Particle pollution includes: PM_{10} (particles with diameters that are 10 µm and smaller); and $PM_{2.5}$ (particles with diameters that are 2.5 µm and smaller). On February 7, 2024, the EPA proposed to strengthen the National Ambient Air Quality Standards for Particulate Matter ($PM_{2.5}$) from a level of 12.0 µm/m^3 to 9.0 µm/m^3.

Fabric-filter dust collector (baghouse). A fabric-filter dust collector (also commonly referred to as a baghouse) collects particulate matter from the fluegas stream (Figure 5). Baghouses are essentially like a giant vacuum cleaner, except that they contain hanging filter bags, and the dust is collected on the bags' surface. Located on top of the bags is a cleaning system that blows pressurized air in short pulses into the bags, forcing the dust to fall into the hoppers underneath.

Fabric filters can handle extremely high quantities of dust. A properly designed system can be extremely efficient. Thanks to the self-cleaning system, baghouses can continuously operate for years and years. Fabric filters cannot, however, deal with very moist or sticky dusts, tars or oily matter.

Wet electrostatic precipitator (WESP). A WESP uses an induced electrostatic charge to remove particulate-matter emissions in exhaust-gas streams, in situations where the gas stream is already wet, such as downstream of a wet scrubber. The WESP applies a negative voltage of several thousand volts to an electrode grid, creating an electric corona discharge that ionizes the particles and droplets in the moisture-saturated gas stream (Figure 6).

The ionized particles and droplets then migrate toward the grounded plates or tubes, where they collect. This use of electrostatic force means the system has no moving parts. The collected particles and droplets are washed down via wash cycles and discharged through the water-deluge system.

A WESP removes aerosols, mists, ultra-fine particulate matter (submicron), organic particulate matter and sticky particulate matter. This includes particulate matter that is moist, sticky, tarry and oily. A WESP has no barriers to gas flow, resulting in a low pressure drop. Unlike the baghouse, a WESP is unable to handle large inlet loadings of particulate matter. In certain applications,

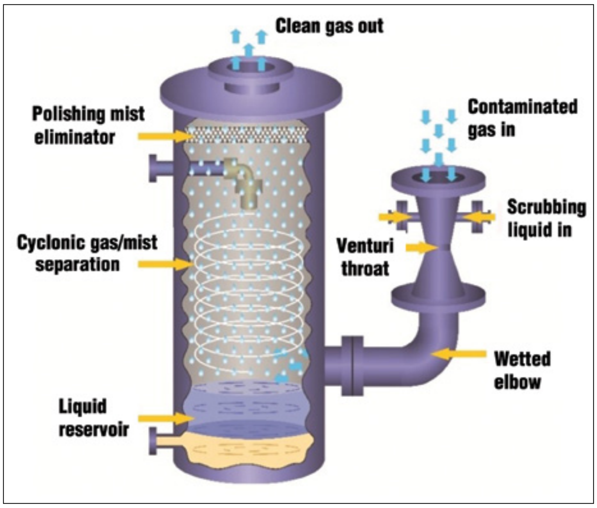


FIGURE 7. Venturi scrubbers have been used for over a century to remove particulate matter from gas streams

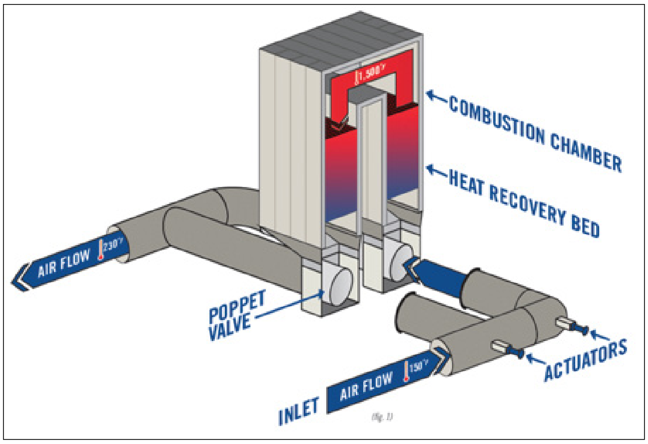


FIGURE 8. Regenerative thermal oxidizers can achieve thermal efficiencies as high as 95–97%

a WESP is an excellent APC system to be placed before a regenerative thermal oxidizer, as it protects the ceramic media bed.

Venturi scrubber. A Venturi scrubber is another type of wet scrubber used for particulate-matter collection. The design of the Venturi scrubber typically allows for the vertical downflow of gas through the Venturi throat (Figure 7). The gas makes contact with a scrubbing liquid, and the resulting liquid droplets trap dust particles. This mixture enters a cyclonic separator, allowing for the separation of particulate matter, resulting in the exit of clean gas.

Venturi scrubbers are an old technology that has been used for over 100 years. They are optimized for particulate-matter capture and can be especially effective for dust that is sticky or moist. A downside to consider is that Venturi scrubbers can potentially create very large pressure drops in the gas stream, resulting in high energy consumption for downstream fan equipment.

VOCs and HAPs

For VOCs and HAPs, an oxidizer technology is usually most suitable.

Regenerative thermal oxidizers (RTO). RTOs are used to destroy VOCs and HAPs, including odor-causing compounds. RTOs are highly effective and are the most commonly used oxidizer for this purpose. Most regenerative thermal oxidizers have a destruction removal efficiency of 95 to 99%, with certain models achieving greater than 99%.

The RTO's destruction efficiency relies on "The Three Ts:" high temperature, time and turbulence. This means that the process must occur at the correct high temperature, for the correct duration and have the proper airflow to mix. RTOs are efficient at regenerating thermal energy to reduce operating costs. Keep in mind that the RTO's operating process is dependent on a temperature that typically ranges between 1,400 and 1,700°F.

The thermal regeneration, which drives the fuel savings of the burner, occurs in the heat-recovery chamber. This chamber is filled with ceramic media, suited for the gas constituents, to absorb the hot gases from the combustion chamber (Figure 8). While one ceramic media bed is heating up with the exhaust gas, the other

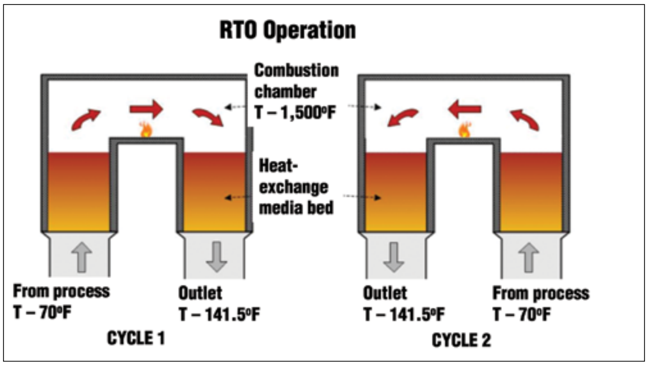


FIGURE 9. Thermal regenerative technologies usually employ two chambers in tandem to help improve heat recovery

ceramic media bed is preheating the process gas to reduce the fuel needed to achieve the target destruction temperature (Figure 9). The process gas flow direction is changed as denoted between Cycle 1 and Cycle 2. The typical thermal efficiency of an RTO is between 95 and 97% on a mass-corrected basis.

Regenerative catalytic oxidizer (RCO). A regenerative thermal oxidizer can become a regenerative catalytic oxidizer with the addition of a catalytic ceramic-media layer. The added catalyst allows for VOC destruction at a much lower temperature. The lower temperature leads to lower energy consumption when compared to an RTO.

RCOs are very efficient at destroying VOCs and HAPs, including odors. RCOs tend to be more energy efficient than standard RTO units and have a destruction efficiency that can be greater than 99%. RCOs may also be the better economic choice in situations where the VOC concentration is low or burner fuel costs are high. Keep in mind that RCOs cannot be used when certain pollutants are present in the gas that will destroy the catalyst material.

Direct-fired thermal oxidizer (DFTO). A direct-fired oxidizer is a thermal oxidizer utilized to destroy VOCs and HAPs that is not regenerative. Like the RTO, a direct-fired oxidizer uses thermal oxidation to destroy pollutants. Unlike a regenerative thermal oxidizer, a direct-fired oxidizer solely utilizes a burner to heat the pollutants without a ceramic media bed to capture the heat post combustion chamber or preheat the process gas before the combustion chamber. DFTOs are best for exhaust streams with high concentrations of pollutants, low flows, or that are not used continuously. ■

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All images provided by the author

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Regenerative H_2S-Removal Technologies for Biogas Upgrading

Advances in H_2S-removal technologies for biogas upgrading are essential for mitigating environmental issues like air pollution and corrosion

Christopher Ristevski and Rosanna Kronfli
Macrotek Inc.

Biogas, a renewable energy source derived from organic waste and typically comprised mainly of methane, holds great promise for sustainable energy production. However, the presence of hydrogen sulfide (H_2S) in biogas poses challenges to its utilization due to its corrosive and toxic nature. Effective removal of H_2S is crucial for upgrading biogas to meet quality standards for various applications, including power generation and injection into natural gas pipelines.

This article explores the different types of H_2S removal technologies for biogas upgrading, with a focus on the advantages of regenerative technologies in addressing the unique challenges of H_2S removal.

Biogas produced from anaerobic digestion processes often contains impurities, with H_2S being a predominant contaminant. While H_2S is naturally occurring, its presence in biogas streams can lead to equipment corrosion, air pollution and health hazards. Therefore, upgrading biogas to remove H_2S is essential for ensuring safety, protecting infrastructure integrity and complying with regulatory requirements. Moreover, purified biogas can be utilized efficiently in various applications, contributing to more sustainable energy practices and reducing reliance on fossil fuels.

H_2S removal technologies

Several technologies are available for removing H_2S from biogas streams, each with its own unique mechanisms and advantages.

Chemical scrubbing. Chemical scrubbing involves removing H_2S by absorption and neutralization. A base, such as sodium hydroxide or potassium hydroxide, is metered into the scrubbing liquid and reacts with the H_2S to form salts. Often, an oxidizing agent, such as sodium hypochlorite, is added to convert unstable sulfite salts to stable sulfate salts. Chemical scrubbing is not selective to H_2S, and CO_2 interference can result in increased chemical consumption. While effective, chemical scrubbing requires significant chemical consumption, especially if CO_2 is present. It also generates large volumes of wastewater, which increases operating costs.

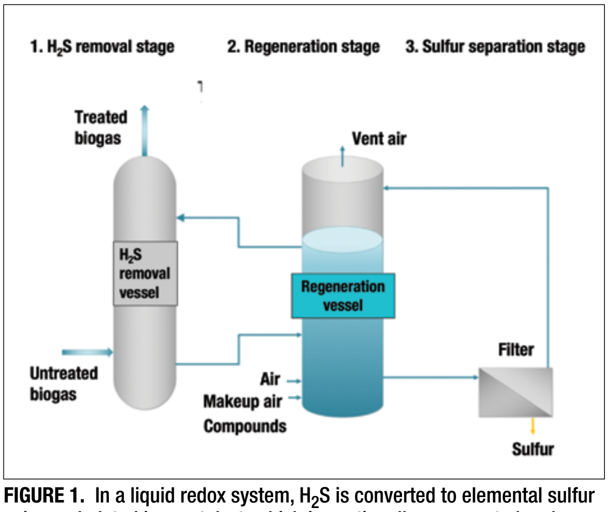

FIGURE 1. In a liquid redox system, H_2S is converted to elemental sulfur using a chelated iron catalyst, which is continually regenerated and re-used in the system

Biological desulfurization. Biological desulfurization utilizes sulfur-oxidizing microorganisms to convert H_2S into elemental sulfur or sulfuric acid. This regenerative process occurs in bioreactors or biofilters, offering a sustainable and environmentally friendly approach to H_2S removal. However, biological desulfurization may be limited by process kinetics and sensitivity to operating conditions.

Adsorption. Adsorption technologies involve the physical adsorption of H_2S onto porous media, such as activated carbon or zeolites. Adsorption offers versatility and can achieve high removal efficiencies, but the spent adsorbents require regeneration or disposal, adding to operational costs.

Scavengers. Scavengers are chemicals, such as metal oxides or triazines, that irreversibly react with H_2S. For both adsorption and scavengers, a standby unit is often installed in order to replace the spent media without interrupting the process. While effective, scavengers generate waste products that require disposal, contributing to environmental concerns and operational costs.

Liquid redox. Liquid redox systems (Figure 1) utilize a catalyst, such as chelated iron, to convert H_2S into solid sulfur. The chelated

TABLE 1. COMPARISON OF H_2S REMOVAL TECHNOLOGIES				
Process features	Regenerative technologies	Chemical oxidation	Scavengers and fixed-media beds	Bio-filters
Minimal waste generation	✔	✘	✘	✘
Regenerative reagent	✔	✘	✘	✔
Low reagent consumption	✔	✘	✘	✔
Non-toxic reagent	✔	✘	✘	✔
Usable byproduct generation	✔	✘	✘	✔
Low freshwater requirement	✔	✘	✔	✔
High turndown	✔	✔	✔	✘
Ability to handle process variability	✔	✔	✔	✘
Low operating costs	✔	✘	✘	✔
Low capital costs	✔	✔	✔	✘

iron is not consumed in the process and the only losses are typically due to degradation over time. Liquid redox offers a sustainable solution for H_2S removal by minimizing chemical consumption and waste generation. This technology regenerates and recycles the active catalyst used in the removal process, reducing operational costs and environmental impact.

Regenerative technologies

While all H_2S removal methods aim to mitigate environmental risks and enhance operational efficiency, regenerative liquid redox technologies offer distinct advantages that make them increasingly attractive for biogas producers and industrial applications (Table 1). The following sections cover the multifaceted benefits of regenerative technologies, emphasizing their pivotal role in advancing process sustainability, cost-effectiveness and operational flexibility.

Environmental sustainability. One of the paramount advantages of liquid redox technologies lies in environmental sustainability. Unlike conventional chemical-scrubbing methods, which often entail significant chemical consumption and waste generation, liquid-redox technologies minimize environmental impact by optimizing reagent usage and promoting circular-economy principles.

Chemical consumption reduction. Liquid-redox desulfurization systems operate on regenerative principles, where reagents are continuously regenerated during the H_2S removal process. For instance, chelated iron catalysts facilitate the oxidation of H_2S to elemental sulfur, which can be separated from the process liquid through filtration, and recycled back into the process, minimizing the need for continual reagent makeup. Minimal chemical makeup is required to maintain the system pH.

Waste minimization. By significantly reducing chemical consumption and promoting reagent recycling, liquid-redox inherently minimizes waste generation. The continuous regeneration and reuse of reagents results in fewer waste byproducts compared to traditional chemical scrubbing methods. Consequently, biogas upgrading facilities employing regenerative technologies contribute to a more sustainable waste-management ecosystem and reduce their overall environmental footprint.

Cost-effectiveness. While upfront capital costs may be a consideration, liquid-redox technologies offer compelling long-term cost advantages that position them as economically viable solutions for biogas upgrading. Recent advancements in the technology have brought down capital costs, making it a feasible option for a wider range of applications. Furthermore, a modular design philosophy and skid-packaging can reduce installation time and

FIGURE 2. A skid-mounted pump package and modular vessels can minimize field work and installation costs for liquid-redox systems

costs (Figure 2). The inherent efficiencies of regenerative processes translate into substantial savings over the operational lifespan of H_2S removal systems.

Reduced operational costs. One of the primary cost advantages of liquid redox technologies stems from their ability to minimize operational expenses associated with chemical procurement, handling and disposal. By recycling or regenerating reagents, liquid redox desulfurization systems significantly lower ongoing chemical consumption, leading to substantial cost savings in the form of reduced chemical procurement and waste-disposal expenses and ultimately lower payback period depending on the application.

Enhanced lifecycle economics. Despite potentially higher initial capital investments compared to conventional methods, regenerative technologies offer superior lifecycle economics driven by their reduced operational costs and longer-term sustainability, especially for applications with a high inlet loading, because the cost per unit of H_2S treated is lower than non-regenerative technologies. The ability to reuse or regenerate reagents extends the lifespan of H_2S removal systems, maximizing return on investment (ROI) and delivering cost-effective solutions for biogas producers over the system's operational lifetime.

Reduced water requirements. Since minimal waste is generated from liquid-redox technologies, there is a minimal water-makeup requirement compared to other technologies. The quality of water is an important consideration. Water that has low hardness, low dissolved solids and is free of solids and bacteria is beneficial for the process.

Operational flexibility. Liquid-redox technologies offer a high turndown and operational flexibility, enabling biogas producers to adapt to fluctuating feedstock compositions, process conditions, and operational requirements while still maintaining a high H_2S-removal efficiency. This inherent flexibility enhances system resilience, reliability and adaptability in dynamic operating environments (Figure 3).

Robust performance. Liquid-redox desulfurization systems demonstrate robust performance across a wide range of operating conditions, including variations in biogas composition, flowrates and H_2S concentrations. The regenerative nature of the technologies ensures consistent and reliable H_2S removal efficiencies, even in challenging operating environments, thereby minimizing disruptions and downtime.

FIGURE 3. H_2S removal systems should be designed for a high degree of process flexibility

Adaptability to process variability. Biogas production processes are inherently dynamic, with variations in feedstock composition and operating parameters. Liquid-redox technologies offer inherent adaptability to process variability by leveraging automated controller and instantaneous chemical reactions. This adaptability enables seamless integration with anaerobic digestion processes and enhances system stability and performance in diverse operating conditions.

Compliance and safety. By efficiently removing H_2S from biogas streams, regenerative technologies ensure compliance with regulatory standards and safety requirements. Purified biogas is free from corrosive and toxic H_2S, safeguarding equipment integrity and protecting human health and the environment.

Innovations in H_2S-removal technologies for biogas upgrading are essential for advancing sustainable energy practices and mitigating environmental impacts. While various methods are available, regenerative technologies, such as liquid-redox, offer superior sustainability, cost-effectiveness and operational flexibility. ■

Edited by Mary Page Bailey

All images provided by the authors

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Modular Construction: Choosing the Optimal Module Type

Plant process modules are not a one-size-fits-all solution. These considerations can help determine the best size for your project

Mauricio Villegas
Koch Modular Process Systems, LLC

With the growing recognition of the advantages of modular construction over traditional field construction [*1, 2*], it's no surprise that an increasing number of companies across all chemical markets are maximizing the modularization of their facilities. This shift in methodologies aims to reduce project delivery risks, achieve substantial cost savings, and gain scheduling advantages, while accelerating the commercialization of decarbonization technologies worldwide [*3*]. This trend isn't unexpected. As equipment, raw materials, craft labor, and other associated construction costs continue to escalate, coupled with labor shortages and higher project financing interest rates compared to just a few years ago, both owners and investors are turning to modularization as a project delivery model to minimize expenses, limit peak site manpower and worker density, and mitigate overall risks. This strategic move ensures that future projects remain financially viable and can meet investment decision gates. However, while modularization can address many of these challenges and offer substantial benefits, it's essential to recognize that it's not a one-size-fits-all solution.

FIGURE 1. Truckable biochemicals module prepared for transport to the project site for final installation

Modules can be categorized into three types: truckable, conventional and mega. Various factors, such as size, weight and site location, are critical in determining the optimal module type for a project. Sometimes, a blended approach with two or more module types can accommodate the requirements of larger, more complex projects. Before discussing the benefits and drawbacks of each module type, understanding what constitutes a module and what does not is pivotal.

What is a module?

Modules, regardless of size, exhibit two distinct characteristics that differentiate them from traditional field-erected construction and other pre-assembled units.

Modular design. Modules comprise a structural steel frame housing all related process equipment, seamlessly integrating into either greenfield or brownfield plants along predefined interfaces. Unlike pre-assembled units (PAUs), such as pre-assembled pipe racks (PARs) and skids (packaged equipment), modules are complete, scalable, and repeatable systems containing all process-related equipment. This equipment includes columns, vessels, reactors, heat exchangers, pumps, vacuum systems, filters, all field instruments, piping, pipe supports, thermal insulation, tracing, electrical wiring, control cabinets or junction boxes, control systems, and ancillary equipment such as lighting, fire safety, and eyewash stations.

FIGURE 2. This plastics recycling process plant is comprised of twenty-five interconnected truckable modules

Offsite construction. Modular construction takes place at an offsite fabrication yard. Once construction is complete, the modules are transported to the final installation location by land or sea using trucks, rail, barges or ships. Offsite module fabrication yards vary in proximity, from local to international, depending on factors, such as experience, capacity and water access. Relocating construction activities offers several benefits, including reductions in project site congestion, increases in labor availability, enhancements in productivity, and improvements in safety and quality performance.

Different types of modules

As stated earlier, there are three module types: truckable, conven-

FIGURE 3. Shown here is a truckable module fabricated in a horizontal orientation

tional, and mega. Understanding the varying characteristics of each module type enhances discernment when selecting the most suitable mix of attributes based on a project's design and delivery requirements.

Truckable modules. As the name suggests, truckable modules (Figure 1) are primarily transported by road from an offsite fabrication shop to the final installation location using heavy haul trucks. Known for their smaller footprint compared to conventional and mega modules, they typically measure 12 ft × 14 ft, have lengths up to 80 ft, and weigh up to 100 tons. Truckable modules are ideal for small to mid-capacity projects or downstream processes without nearby water access, where columns have diameters less than 7 ft and tanks and reactors are less than 10 ft. Depending on the road conditions between the fabrication shop and the installation location, minor adjustments may be made to the modules' dimensions. They can reach most project locations without specialized trailers or lifting equipment and can also be transported by rail, water, or air if project constraints require it.

The design of truckable modules is flexible. Process systems can be consolidated into a single module for smaller projects with minimal unit operations. In larger projects with multiple unit operations and increased throughput, systems can be divided into multiple modules to form a complete unit when interconnected at the project site (Figure 2). Depending on the project's requirements, modules can be installed horizontally, vertically or stacked. Alternative approaches, such as a hybrid solution or larger conventional modules, should be considered for projects too large for the requirements of truckable modules.

Unlike larger conventional modules, truckable modules are usually constructed horizontally (Figure 3) utilizing an assembly-line approach in controlled environments, such as an enclosed fabrication shop — increasing overall project productivity, quality, and safety. Upon delivery to the project site, these modules are erected and installed vertically unless the design dictates a horizontal installation.

The advantages of truckable modules are key to decarbonization projects with hub-and-spoke deployments [*4*]. They allow incremental capacity additions as feedstock availability and off-take agreements expand. They can also replicate and transport seamlessly across diverse site locations, an added benefit for global commercialization. Furthermore, constrained brownfield projects with limited accessibility should consider truckable modules, as they offer easy navigation within the facility and straightforward installation.

Conventional modules. Before the emergence of highly specialized truckable and mega-modules, conventional modules (Figure 4) were considered the industry standard. Falling just short of the threshold for mega-module classification, conventional modules typically measure around 240 ft × 140 ft, can have a height of 120 ft, and weigh up to 6,000 tons. Since they are not constrained by column, vessel, reactor, and tank sizes, conventional modules are an ideal option for large-capacity projects where most equipment sizes exceed the capacity of truckable modules.

Constructing a conventional module is similar to traditional field construction with the exception that it is conducted at an offsite fabrication yard. Since construction is vertical in orientation and outdoors, safety, cost, and quality benefits are reduced due to the exposure to natural elements and requirements of additional equipment such as cranes, man-lifts and scaffolding. However, the benefit of less site congestion is apparent since the construction is at an offsite location.

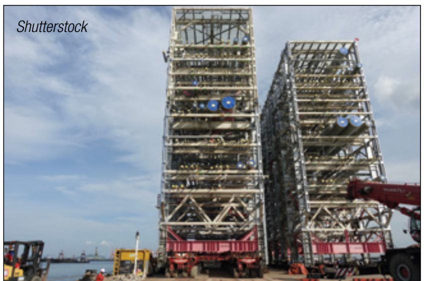

FIGURE 4. Self-propelled modular transporters (SPMTs) prepare to transport conventional modules a short distance via land to a nearby port

Choosing an optimal location for a fabrication yard is critical for transporting conventional modules. These large-scale modules are designed and constructed to include multiple unit operations, and thus, a single conventional module is of considerable dimension and weight. Due to this, they cannot travel along most public roads and highways and can only travel short distances on land. If the fabrication yard is not adjacent to the project site, water transportation is another option (Figure 5).

For longer distances requiring water transport, temporary structural steel is required to secure the modules to barges, adding more than 25% to structural steel costs and labor hours as compared to <5% with truckable modules. Ideally, conventional module construction occurs at large domestic or international fabrication yards with sufficient capacity, material handling equipment, labor and water access or temporary fabrication yards near a project site.

Whether transporting conventional modules from the fabrication shop to a barge for water transport or to the project site location, specialized trailers, such as self-propelled modular transporters (SPMTs), assist in moving them to their destination (Figure 6). These remotely operated multi-axle trailers can carry upwards of 60 tons per axle and can be connected in series to accommodate heavy hauls. While this is an additional expense, it is key to note that tools and options are available to support the transportation of conventional modules.

Mega modules. Tailored for world-scale projects exceeding $1 billion, mega modules are characterized by their complexity and extremely

FIGURE 5. Conventional modules are transported by water from an overseas fabrication shop to the project site for installation

FIGURE 6. This offshore mega module is being transported by SPMT to prepare for water transport to final destination

large size, with units often weighing over 6,000 tons, some reaching up to 25,000 tons. Like conventional modules, mega modules are constructed vertically and subject to transportation and fabrication yard requirements. However, the number of fabrication yards capable of handling mega modules is limited, posing challenges in the availability and cost of specialized transportation vessels, such as roll-on roll-off (RO-RO) vessels, heavy haul trailers, hydraulic jacks and lifting equipment.

Mega modules scale up the strategy of truckable modules, integrating multiple conventional modules into a comprehensive system called a mega module. This integration often eliminates conventional pipe racks, reducing the project footprint and overall piping quantities. Opting for a mega module project capitalizes on economies of scale and access to low-cost labor centers. By constructing a single mega module, the number of shipments and infield inter-module tie-ins is minimized, enabling extensive pre-commissioning and commissioning activities at the fabrication yard and facilitating comprehensive pretesting before shipment.

Typically, mega modules are constructed in world-class fabrication yards located overseas in Southeast Asia, leveraging lower-cost labor, materials and equipment. However, executing a mega-module project requires meticulous planning and flawless execution in various aspects, such as design control, project management, interface and change management, supply chain management and transportation. Therefore, selecting a seasoned and experienced project management team is essential.

Selecting the right module type

Selecting the best modular type for a project is a critical decision that can significantly impact overall project success. While modular construction offers numerous advantages, such as reduced project delivery risks, cost savings, and scheduling benefits, it's essential to recognize that modules are not a one-size-fits-all solution. Understanding the characteristics and benefits of each modular type will aid in determining the optimal delivery model for a project's unique requirements.

Regardless of which modular type is selected, the common and most important factor is that the decision to go modular needs to be made as early as possible. A change in strategy post-pre-feed will have a greater impact on the project's cost and schedule and alter the sequence and early timing of some engineering efforts. Therefore, to ensure the greatest opportunity for success, owner's should engage internal and/or external modular construction subject matter experts to perform a study as early as FEL-1 (feasibility), if possible, to determine the best modular type for the specific project requirements.

Blended delivery

Another great quality of modular construction is the flexibility in design. A blended modular project delivery can be used for mega or large projects, combining two or more module types to leverage their unique advantages. Project stakeholders should consider project objectives, site conditions, transportation logistics, and budget when selecting the appropriate modular delivery model. By evaluating these factors and understanding each module type's nuances, stakeholders can maximize the benefits of modular construction and ensure project success. ■

Edited by Gerald Ondrey

References

1. Villegas, Mauricio and Loftus, Chris, Modularization: Managing Project Delivery Risk in the Time of COVID, *Chem. Eng.*, June 21, 2021, pp. 35–39.
2. Halford, Susan and Kretzschmar, Tony, Practical Solutions to Modular Project Execution, *Chem. Eng.*, June 2017, pp. 44–50.
3. Villegas, Mauricio and Schafer, Tom, www.processingmagazine.com/home/article/21233990/truckable-modules-paving-the-road-for-advantageous-construction-solutions.
4. Villegas, Mauricio and Schafer, Tom, Decarbonization is at the Forefront of Environmental Innovation, *Hydrocarbon Processing*, January 2023.

Acknowledgment

All figures courtesy of Koch Modular Process Systems, unless otherwise indicated.

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How to Conduct a Thermal Audit of an Industrial Facility

The efficiency of steam-generating and distribution systems can be improved incrementally, but more substantial gains can be found using pinch analysis for better heat recovery

Patricia Provot
Armstrong International

When it comes to improving the energy efficiency of a thermal system, most industrial organizations focus on making incremental improvements to their utilities. Typically, these incremental improvements will provide up to 5–10% in energy savings and CO_2 emission reductions, with payback times that are under three years. Chemical process industries (CPI) facilities, however, are increasingly looking at completely decarbonizing their facilities, and therefore, are looking beyond the traditional ways of utilizing thermal energy and increasingly pursuing an approach that aligns with principles of the circular economy. By applying circular principles to industrial thermal systems, plant managers can recover massive amounts of energy that have traditionally escaped the facility as waste heat. When this waste heat is put back into the process, it can result in up to 30–50% reductions in energy use and CO_2 emissions. This article describes how to conduct a thermal audit at a CPI site to explore areas ripe for energy savings.

Incremental improvements

Within most industrial facilities, steam is used as the medium to provide heating for process or building applications (Figure 1). These steam systems, however, are often very old and are likely to have been reconfigured multiple times as the facilities or processes change, resulting in the loss of efficiency over time. This is a drain on a company's bottom line, but it also negatively affects an organization's ability to continue operating, as regulatory bodies have been tightening their emission standards in recent years.

The stakes are high, so it is vital to understand a system's energy consumption, in addition to its level of CO_2 emissions, safety and reliability. All of these can be evaluated via a thermal audit.

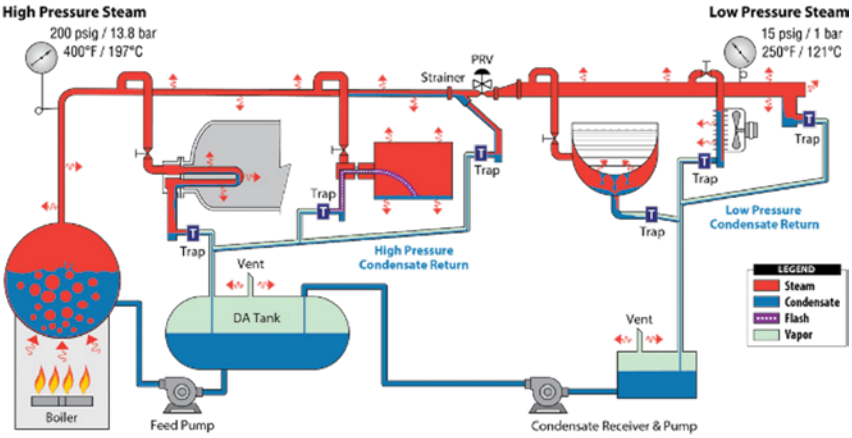

FIGURE 1. The diagragm shows a typical steam system, includign steam generation, steam distribution, steam use and condensate return systems

Auditing steam generation

It is possible for typical steam systems to operate at up to 80% efficiency, but very often, they operate at only 60% efficiency due to a number of factors that can be mitigated after a thermal audit.

A thermal audit begins with measuring the efficiency of a plant's steam-generating equipment — determining how much energy is consumed (using fuel meters) in the boilers and how much energy is produced (using steam flowmeters).

In the boiler house, the first place to look is boiler stack temperatures and determine whether more energy can be recovered through the installation of an economizer, a condensing economizer, or by improving the existing economizers (Figure 2). Next, measure the percentage of condensate that is returned to the boiler. Ideally, all steam not directly used in the process should be returned as condensate. Failing to reclaim and reuse condensate contributes to energy losses.

The quality of make-up water added to the boiler should also be examined, because higher water quality leads to lower boiler blowdown losses. Next, identify the resulting boiler blowdown requirement and confirm whether a boiler blowdown heat-recovery system has been installed.

Finally, measure the quality of the combustion to identify whether the system is maintaining the correct level of excess oxygen for the fuel used, and if the air flowing into the boiler could be pre-heated. Typically, plants will have some of these improvements implemented, but rarely all. Each of these improve-

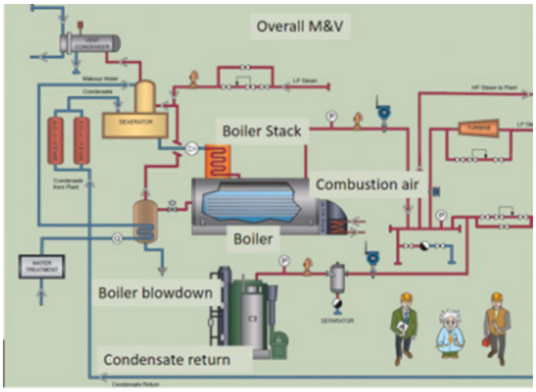

FIGURE 2. Areas of potential optimization in the boiler house are shown here

ments can help with reducing the energy bill and consequent CO_2 emissions. The breakdown of savings includes the following:

- Boiler blowdown heat recovery — 1% energy reduction
- Stack economizer — 4% energy reduction
- Stack condensing economizer — 6% energy reduction
- O_2 trimming — up to 1.5% energy reduction
- Air preheating — Up to 1% energy savings

From a reliability standpoint, it is important to understand the dryness of the steam produced. Steam that is not dry enough will create erosion in the system and will have a negative impact on heat transfer. Steam dryness can be measured with an instrument or can be measured manually by calculating the energy contained in the steam via a bucket and stopwatch test.

Steam dryness should be above 97% (that is, the steam should contain less than 3% water droplets in suspension). If the steam quality is very poor (generally considered to be steam dryness of less than 95%), it could lead to destructive waterhammer and result in a safety hazard.

It is also important to have a sufficient number of flowmeters in the boiler house to track key performance indicators (KPIs) on a regular basis and assess deviations. This could help identify a sudden drop in boiler efficiency or a reduction in condensate return from the plant.

Steam distribution audit

A steam distribution network in a chemical process facility is usually lengthy, which means there are a lot of areas where energy can escape. Using a thermal imaging camera, it is possible to check both the state of the insulation surrounding the steam lines, and view the valve and pipe accessories that are not insulated at all (Figure 3). Another important item is ensuring the steam system is drained properly from condensate to avoid waterhammer, which could result in safety incidents (Figure 4).

And finally, ensure that the steam traps are tested at least on an annual basis and that failed steam traps are replaced. A best practice is to manage all the steam traps in a database, track their performance and maintain a failure rate below 5% (Figure 5).

Each of the following improvements can help reduce the energy bill and consequent CO_2 emissions:

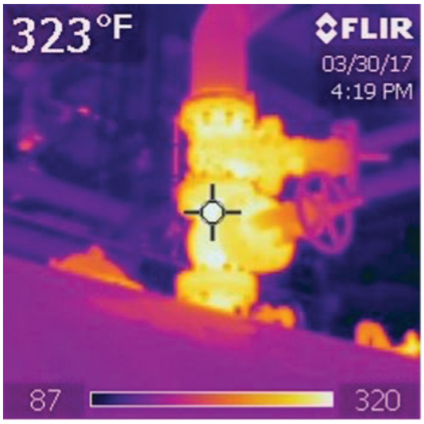

FIGURE 3. In this infrared image of a non-insulated valve, temperature differences can be observed

- Insulation improvements — 2.5% savings
- Steam trap management — 3.5% savings

Condensate return

Finally, at the process level, it is important to review how condensate is returned. Low-pressure steam users might have stall issues. This means that the pressure in the heat ex-

FIGURE 4. The photo depicts a valve that was damaged by waterhammer

changer is lower than the condensate return pressure and the condensate cannot be returned by gravitational means. Very often, these applications will end up draining condensate locally through a bypass valve. In order to return that condensate, a pumping system will be necessary.

When steam is used at higher pressure, it is smart to check whether it is feasible to use flash steam (condensate re-vaporization once it reaches lower pressures) in a nearby application, which can help reduce steam use and consequent energy.

Each of the following improvements can help reduce the energy bill and consequent CO_2 emissions:

- Condensate return — up to 3% energy reduction
- Flash steam recovery — up to 1% energy reduction

Typically, when performing a full audit of a plant, 5–10% energy reduction will be found through projects with a 1–3 year payback. These projects are often referred to as quick wins (Figure 6).

A circular approach to energy

Applying a circular methodology (or "approach") to thermal energy can help reduce up to 30–50% of energy consumption in CPI plants. However, it requires a change in perspective, moving away from following the thermal system and incrementally improving it, to understanding the process and its needs. What does the process really require?

Do you need steam? A lot of facilities use steam at higher pressures and temperatures because it is an easy medium to produce and distribute (steam requires 100 to 1,000 times less space than water and requires smaller-diameter piping to distribute). But very often, the process does not require these higher temperatures.

In the quest for net-zero emissions, the question becomes "why should we use a steam system that is 60–80% efficient in processes where temperatures below 248°F are needed?" At those temperatures, hot water can be used in systems that are >90% efficient.

Where is the energy going? In a CPI facility, most of the energy used ends up being lost into the atmosphere. Simply stated, the first law of thermodynamics tells us that energy cannot be destroyed or created — its quantity within a system remains stable. When energy is put to work, sometimes by converting it from one form to another, it is degraded to a lower quality of energy. So, if energy in an industrial plant is degraded but not destroyed, how does it leave the plant?

Currently, primary energy is brought into a plant in the form of electricity and fossil fuels. In a typical factory, less than 20% of incoming energy is used for moving things (motors converting electricity into mechanical energy) or lighting the facilities. Due to energy efficiency, part of this energy eventually ends up as waste heat that increases the building's interior air temperature. Does that mean that the remaining 80% of the primary energy used for thermal is going into the products being manufactured? Not exactly. In most industries, only a small portion of the primary energy is converted into chemical energy contained in the final product. Furthermore, the input materials used in manufacturing are usually at the same (often ambient) temperature as output products when leaving the plant. In fact, the majority of primary energy ends up as waste heat that is frequently lost through stacks, cooling towers and sewage.

The circular approach aims to maximize heat recovery in a plant to drastically reduce the energy needed to operate it and maintain its processes. When applying this, the following methodology of pinch is used.

Pinch analysis

Pinch analysis is a methodology for minimizing energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat-recovery systems, energy supply methods and process operating conditions. It is also known as process integration, heat integration, energy integration or pinch technology.

The pinch methodology involves mapping all heat sources (processes that are cooled down and where energy is removed) and heat sinks in the facility (processes that require heat and where energy is added).

For each of these heat sinks and heat sources, we identify the temperatures available, the kilowatts needed to be added or removed, and seasonality (is there a different load in summer versus winter, and is the load stable throughout the day and night?).

Thermal mapping can be time consuming if the plant lacks meters to track the processes. In those cases, temporary ultrasonic strap-on flowmeters can be used to estimate the heat sinks and heat sources. Once the mapping is finalized, pinch methodology can be used to identify the heat recovery potential and consequently the minimum amount of energy needed for the plant if all waste heat is recovered.

An engineer can then review the model to define what is practically recoverable. Some of the specifics to be considered include the following:

- Heat sources and heat sinks that are far apart within the plant might

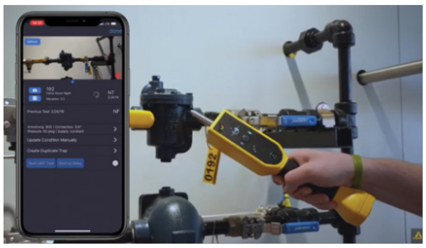

FIGURE 5. Testing steam traps with a handheld automated device can yield valuable information about the steam system

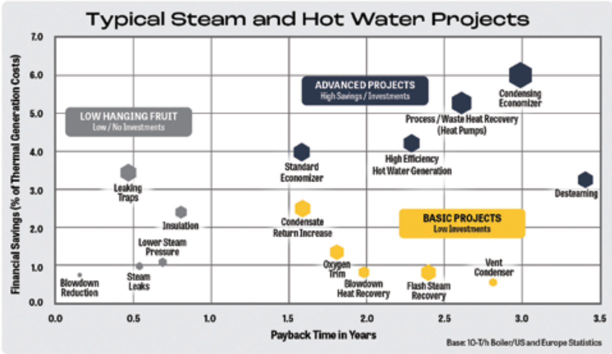

FIGURE 6. The chart shows potential savings and payback times for various "quick-win" steam-system projects

not be practical to recover from a financial standpoint.

• If there is no time synchronization between a heat sink and a heat source, then thermal storage systems will need to be designed.

Heat can be recovered either through direct heat recovery, using heat exchangers and coils, or with heat pumps that can increase the temperature of low-grade heat to make it usable. Industrial high-temperature heat pumps have enjoyed a number of technical advancements recently, and can easily generate 248°F for hot water or even steam.

The author's experience has shown that most of the chemical plants that use low and medium temperatures can operate with 50–70% of thermal energy if they were to apply this methodology.

Creating a pinch model for a facility provides the necessary framework for projects to follow and maximize energy heat recovery. Despite pinch rules sometimes seeming to be counterintuitive, they are effective and will be explained below.

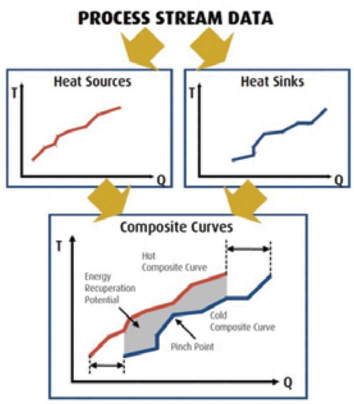

FIGURE 7. Pinch composite curves, like the one shown here, indicates the heat-recovery potential within a system (adapted from Ref. 1)

Pinch model

As shown in Figure 7, the pinch point is the temperature at which the hot composite curve and cold composite curve are the closest. Typically, the pinch point divides the temperature in two regions: heating utility and cooling utility.

Heating utility (steam, hot water) can be used only above the pinch and cooling utility (chillers, cooling towers) below it.

Some takeaways from a pinch model include the following:

• The overlap area (gray area in Figure 7) represents the heat-recovery potential through heat exchangers. There is no need to use heating utility or cooling utility in this area.

• Never cross pinch temperature with heat exchangers. If the pinch point is crossed, a high-grade heat source will be used to heat a lower-grade source, wasting an opportunity of heat recovery at the higher temperatures. This will prevent the system from maximizing heat recovery and, in the end, use more external energy. Not crossing the pinch point is counterintuitive to a lot of engineers looking for quick wins. When the focus is on short payback times, the natural tendency is to take a very hot stream and use it to heat something that is cold. This allows for a high temperature difference on the heat exchanger, smaller heat exchange surfaces and quick payback times.

• Heat pumps have to cross the pinch. Ideally, use the lowest-temperature stream (that cannot be used for anything else) and, with a heat pump, produce the highest temperature for which external energy is needed. A high ΔT will result in a lower coefficient for performance (COP) for the heat pump (COPs will be between 2 and 3), but this is still better than an electrical boiler with a COP of 1. Having a high lift on a heat pump is counterintuitive. Typically, users who are focused on quick wins might try to find applications with lower temperature differentials to achieve higher COPS and higher payback times. But that approach does not make sense from a pinch standpoint. If that application can be completed through direct heat recovery (free heat recovery), there is no need to use a heat pump, which will consume electricity.

Once it is understood that most of the energy used in the plant is wasted, the circular approach really becomes a powerful concept, and pinch analysis helps to maximize that heat recovery.

Incremental gains or circular?

When looking at both quick incremental wins and the circular methodology, it is clear that both are viable strategies for energy reduction, and this is not an either/or situation. While quick wins can yield immediate results, the circular approach offers the potential for substantial long-term reductions in energy consumption — although it may require more significant capital expenses and longer implementation times. In the meantime, some of the quick wins identified above can start the journey toward energy reduction and can begin the process of building a roadmap toward decarbonization. ■

Edited by Scott Jenkins

Editor's note: All photos were provided by the author, except when otherwise noted.

Reference

1. Natural Resources Candada. https://natural-resources.canada.ca/sites/nrcan/files/canmetenergy/pdf/fichier.php/codectec/En/2009-052/2009-052_PM-FAC_404-DEPLOI_e.pdf

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Executive Interview: Clariant Catalysts Business Unit

In this exclusive interview, Jens Cuntze, member of Clariant's Executive Steering Committee, offers his perspective on the goals, challenges and accomplishments of the Business Unit Catalysts, as well as the challenges faced by the chemical process industries

Jens Cuntze is Clariant's business president of the Business Unit Catalysts and the Asia-Pacific (APAC) Region. Cuntze holds a Ph.D. in chemistry from the Swiss Federal Institute of Technology (ETH Zurich), as well as an M.B.A. degree. He started his career as a consultant, and later associate principal at McKinsey with a focus on the chemical industry. In 2003, Cuntze joined Clariant as head of strategic planning for the Division Life Science & Electronic Chemicals, followed by several management positions in the business and in corporate functions. From 2013 until 2018, he held the positions of vice president and head of the Business Segment Petrochemical Catalysts (former Südchemie business), as well as board member of two global joint ventures. Then he served as head of Corporate Planning & Strategy at Clariant until July 2022.

EXECUTIVE INTERVIEW

How would you describe your company?

Clariant is a focused specialty chemical company led by the overarching purpose of "Greater chemistry – between people and planet." By connecting customer focus, innovation, and people, the company creates solutions to foster sustainability in different industries. On December 31, 2023, Clariant had a staff of 10,481 with sales of CHF 4.377 billion for the full year. Clariant conducts its business through the three Business Units: Care Chemicals, Catalysts and Adsorbents & Additives and has its headquarters in Switzerland.

Clariant's Business Unit Catalysts develops and manufactures innovative catalyst solutions that enable chemical producers to increase efficiency, lower emissions and transition toward sustainable production.

With our global reach, established research and development capabilities and broad portfolio, we provide technologies to optimize processes across multiple industries including olefins, syngas and specialties.

What goals are you trying to achieve?

We provide innovative technologies that optimize yields, minimize waste and help decarbonize the downstream markets we serve. As a specialty chemical company, we have a great chance to benefit from and drive the sustainability transformation and will continue to strongly support our customers here. In 2023, sales in Catalysts increased by 9 % in local currency with an increased share of innovation-based sales.

What challenges does your company face?

Clariant showed a resilient performance in 2023 as our business model is characterized by a strong focus on innovation, sustainability and our customers.

For the chemical industry, 2023 overall has been a year of continued challenges, impacted by the uncertain macroeconomic and geopolitical environment, with some weaknesses in end markets.

What challenges do you see for the chemical process industries as a whole?

The chemical process industries (CPI) face several challenges globally and regionally. Access to competitive feedstocks and energy, as well as oversupply, in some of the markets are examples. In China, although economic growth is tending to slow down, due to its size, the market will generate more than half of the growth for the global chemical industry. The market remains very dynamic; however, some industries have built up overcapacities because the recovery of growth fell short of some expectations.

What accomplishments are you most excited about?

In 2023, Clariant's catalyst technologies enabled emission reductions of more than 40 million tons of carbon dioxide equivalent (CO_2e) in customers' chemical processes across a wide range of industrial sectors.

For perspective, this impact exceeds Clariant's total carbon footprint by a factor of eight.

Lighthouse projects, like a large European e-methanol plant, further validate our innovations in decarbonization. Our MegaMax* catalyst will help convert renewable CO_2 into 32,000 tons per year of carbon-neutral methanol for the shipping industry. A large portion of the plant's annual yield is already allocated to the logistics group Maersk for powering its first-ever carbon-neutral maritime fleet.

Another great innovation we launched last year is our cloud-based AI-platform Clarity* that provides customers 24/7 access to their real-time catalyst performance data, as well as access to advanced visualization, analysis and monitoring tools. Clarity supports all Clariant catalyst applications, allowing end-to-end encrypted data sharing, with key performance indicators visualized in customizable dashboards. The user interface also connects customers directly with Clariant's experts for technical exchange and guidance. Since its launch, Clarity has been adopted by more than 90 plants and is serving more than 400 active users in 28 countries around the world. ■

* MegaMax and Clarity are trademarks of Clariant

Department Manager: Dorothy Lozowski

Company: Clariant
Number of Employees: Approximately 10,480
Corporate Headquarters: Muttenz, Switzerland
Locations: 68 production sites
Leadership: Conrad Keijzer, CEO
Main Products: Specialty chemicals
Website: www.clariant.com

Improved Mixing Performance Drives Innovation in Battery Development

Effective slurry mixing for electrode material has a significant effect on the performance of a lithium-ion battery fabricated downstream. A collaboration improved the slurry-mixing ability and improved the quality of the electrode materials

Erin Dillon
Charles Ross & Son Company

The global shift towards cleaner and more sustainable energy sources has accelerated due to increased public demand, legislative measures, policy initiatives, and funding from both public and private sectors. This transition necessitates advancements in technology to reduce emissions and improve energy storage systems, particularly those that integrate renewable energy sources into the existing grid.

A key aspect of improving energy storage is high-performing lithium-ion batteries (LiBs), and a key player in the pursuit of battery technology innovation is the Battery Innovation Center Inc. (BIC; Newberry, Ind.; wwww.bicindiana.com), a non-profit public-private partnership. With its state-of-the-art facilities (Figure 1) and integrated approach to battery research, development, and testing, the BIC is at the forefront of energy storage technology and manages all aspects of the battery and energy storage lifecycle while creating a secure environment for the interchange of information and expertise. This article describes a collaborative project between BIC and original equipment manufacturer Charles Ross & Son Company (Hauppauge, N.Y.; www.mixers.com), where Ross mixers were used to improve the manufacture of electrodes for Li-ion batteries.

Electrode slurry: mixing matters

Battery cell fabrication consists of several steps, including electrode slurry mixing, electrode coating and drying, electrode calendering/densification, electrode slitting, cell fabrication, electrolyte filling, and electrochemical testing. Electrode slurry mixing is highly crucial in the early stage of the process because the quality of mixing directly impacts the overall performance and consistency of the final battery product. The proper ratio of active materials, binders, conductive additives and solvents must be thoroughly combined. Any solid agglomerates should be finely dispersed, while also taking care not to over-shear the slurry, which can negatively impact viscosity, stability and overall battery performance. Through optimal formulation and mixing, slurry rheology is tightly controlled to ensure that both cathode and anode can be applied effectively during the coating and electrode fabrication stages.

As the BIC facility expanded and its customer base grew, the team recognized the necessity to upgrade their smaller R&D laboratory-scale mixers. They sought the expertise of Charles Ross & Son Company, known for its industrial mixing, blending, drying and dispersion equipment. Founded in 1842, Ross Mixers is a leading supplier of mixers to the process industries, including the electronic and energy storage sectors.

Scale-up challenges

Prior to using Ross Mixers, the BIC laboratory depended on a bench-top overhead stirrer, capable of mixing batches under 100 mL, and a centrifugal planetary mixer with a 300-mL maximum working capacity. While these mixers are still being used for smaller experiments, they pose some challenges when scaling up to larger batches. The overhead stirrer was limited by an open-container design, which can lead to some material loss.

Cara Fagerholm, the senior engineer on the Advanced Battery Development team at the BIC, explains, "Mixing action inherently accelerates evaporation due to the increase in

FIGURE 1. The Battery Innovation Center, located in Indiana, conducts research, development and testing of energy-storage systems

surface area for vapor exchange and rise in temperature. This evaporation may seem small, however, even minor adjustments in slurry solids content can cause significant changes in dispersion and viscosity, and therefore affect the coating quality of a material. Coating quality, in turn, impacts electrochemical performance, so it is important to have fine control of solids content in a closed container. Meanwhile, it is also ideal to reduce water uptake to avoid oxidation in LiBs, as this oxidation adds resistance and attenuates electrochemical performance. Therefore, a closed mixing vessel has a large impact on electrode quality."

Though it provides a closed container, the centrifugal planetary mixer faces limitations in volume and relies on particle-particle interactions to generate shear for slurry dispersion. While effective for certain components, it falls short in dispersing some of the new formulations still undergoing development at BIC. This can impact the measurement of the active materials' true capabilities.

Planetary disperser mixers

The BIC testing facility is now equipped with a pair of Ross PowerMix Planetary Disperser Mixers (PDMs). One unit has a volume capacity of 0.5 gal (Figure 2) and the other unit has a capacity of 2 gal.

The Ross PowerMix is a hybrid

planetary disperser designed to impart a combination of high- and low-speed agitation for mixtures that start out very fluid and eventually thicken up throughout the course of the batching process, making it well-suited for batching electrode slurries. Consisting of a planetary stirrer blade and a high-speed disperser blade, the planetary agitator revolves around a central axis while rotating on its own axis. The planetary blade sweeps material away from the vessel's sidewalls and bottom, carrying it to the saw-tooth blade. This speeds up solids wet-out and dispersion while maintaining material and temperature consistency throughout the batch at all times.

The robust mixing capabilities and advanced design of the Ross PowerMix allow BIC scientists and engineers to consistently produce homogeneous slurries with excellent particle dispersion, regardless of battery chemistry.

Mixing trials performed at BIC are essential for fine-tuning electrode slurry formulations. Initial steps in optimization often focus on the mix sequence and powder ratios to ensure good dispersion and high active material (AM) content. A proper mix sequence is necessary to ensure the successful incorporation of powders and assists in monitoring for quality assurance and quality control (QA and QC) metrics along the way. High amounts of AM are preferable, as the AM is what contributes capacity to a cell, and a higher amount of AM allows the cell to demonstrate a higher capacity per total cell mass. The typical next step is to further optimize the formulation by adjusting solids content. The removal of solvent during the coating process for electrode drying is highly energy-intensive, and it can cause damaging stresses on the surfaces of the electrode and at the current collector interface. Hence, a low solvent content or, consequently, a high solids content is a desired outcome.

Since adding the Ross PowerMix, the BIC can efficiently produce slurry for roll-to-roll coating in a single batch, ensuring homogeneity throughout the mixing process. This single-batch approach is preferred over combining multiple batches from the overhead stirrer and centrifugal mixer as it

BIC

FIGURE 2. The Ross PowerMix 0.5-gal capacity mixer produces homogeneous slurries for battery electrode development

minimizes variations and enables the production of consistent and higher-quality electrodes and cells.

"Further, the use of the Ross mixer aids to improve quality control with repeatability and reliability. This is critical for R&D processes where there can be divergent rheological QC metrics for the same degree of dispersion, depending on input materials," Fagerholm explains, "Typically, we can drastically increase the amount of energy input in our Ross mixers, as permitted by the cooling jacket system and capability for overnight mix profiles. This increased mixing energy can improve the dispersion and increase slurry viscosity as particles separate and all possible particle surfaces become solvated, reducing 'free NMP' [*N*-methylpyrolidone]. However, depending on the surface energies of the materials involved, better-dispersed slurries can have a higher or lower rheology result. Surprisingly, cathode active materials can attract other solid particles in the slurry and create more 'free NMP' in the system to reduce the viscosity."

Meanwhile, BIC also observes that polymer strands can become better aligned in the Ross mixer and drop viscosity for shear-thinning binder systems. The use of a single batch of slurry eliminates the potential inconsistencies that can arise from batch-to-batch variations. This improved uniformity facilitates the precise control of key parameters, such as composition and viscosity. The higher-power, semi-automated mixing apparatus also enables BIC to more definitively obtain and monitor these QC parameters, which are critical for the performance and reliability of the final battery cells.

Another benefit is the ability to translate results and rheology upon scaleup. With well-designed materials and mixing order-of-operations, the BIC is often able to seamlessly replicate outcomes from smaller to larger mixers. This has accelerated their R&D timelines, allowing swift scaleup from multiple small-scale slurry trials to the Ross systems with minimal adjustments.

The Ross PowerMix's vacuum-capable design is yet another advantage. Establishing a vacuum in the mixing vessel efficiently removes any air introduced during mixing. Air trapped in the slurry can cause bubbles to form during the coating process, especially on the surface of the current collector. These defects decrease the quality of coated electrodes and can expose bare metal foils during the battery charge and discharge process, which result in internal shorts within the battery. This also causes unwanted side reactions that reduce the capacity and lifecycle of the cell and may result in catastrophic damage during electrochemical testing.

With the agitators vertically oriented, the Ross PowerMix has no shaft seals, bearings, packing or stuffing boxes submerged in the liquid zone. Agitators are raised and lowered into and out of the mix vessel by a hydraulic lift, enabling easy access for cleaning. The Ross mixers at BIC are operated from a 10-in. touchscreen, and the PLC-based controls can be programmed to run mixing, heating and vacuum sequences, which maximizes overall productivity by improving batch-to-batch consistency and reducing operator errors while accelerating product changeovers. ■

Edited by Scott Jenkins

Editor's note: For more information, see the online version of this article at www.chemengonline.com.

Author

Erin Dillon is media and marketing coordinator at Charles Ross & Son Company (710 Old Willets Path, Hauppauge, N.Y. 11788, Phone: 631-254-0500; Email: edillon@mixers.com), a leading manufacturer of mixing and blending equipment. With over 15 years of experience in the marketing and operations industry, she has published numerous whitepapers on the latest advancements in mixing and blending technology, providing valuable insights to industry professionals.

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Economic Indicators

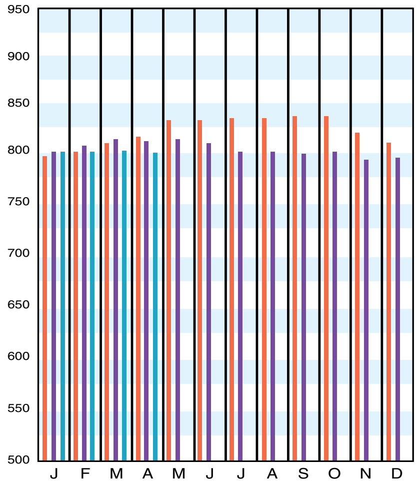
2022 2023 2024

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX® (CEPCI)

(1957–59 = 100)	Apr. '24 Prelim.	Mar. '24 Final	Apr. '23 Final
CE Index	799.1	800.7	803.3
Equipment	1,003.6	1,006.3	1,014.3
Heat exchangers & tanks	805.0	810.6	832.8
Process machinery	1,036.9	1,034.1	1,041.8
Pipe, valves & fittings	1,340.1	1,342.5	1,397.5
Process instruments	574.9	569.8	567.2
Pumps & compressors	1,538.0	1,537.8	1,387.9
Electrical equipment	822.6	822.8	796.5
Structural supports & misc.	1,122.3	1,131.2	1,128.3
Construction labor	375.6	374.6	362.9
Buildings	809.5	812.6	808.5
Engineering & supervision	316.8	315.5	313.8

Annual Index:
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8
2022 = 816.0
2023 = 797.9

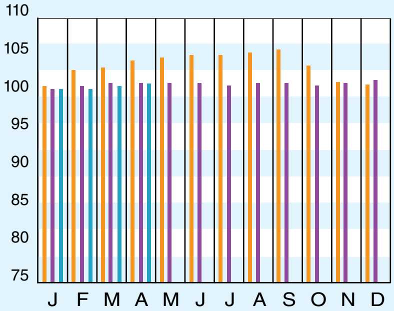


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

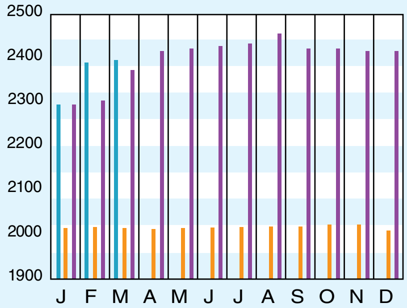
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2017 = 100)	Apr. '24 = 99.6	Mar. '24 = 99.5	Feb. '24 = 99.5	Apr. '23 = 99.6
CPI value of output, $ billions	Mar. '24 = 2,444.8	Feb. '24 = 2,423.5	Jan. '24 = 2,361.8	Mar. '23 = 2,359.5
CPI operating rate, %	Apr. '24 = 78.5	Mar. '24 = 78.6	Feb. '24 = 78.7	Apr. '23 = 79.6
Producer prices, industrial chemicals (1982 = 100)	Apr. '24 = 308.2	Mar. '24 = 298.4	Feb. '24 = 296.1	Apr. '23 = 329.1
Industrial Production in Manufacturing (2017 =100)*	Apr. '24 = 99.4	Mar. '24 = 99.7	Feb. '24 = 99.5	Apr. '23 = 99.9
Hourly earnings index, chemical & allied products (1992 = 100)	Mar. '24 = 227.0	Feb. '24 = 226.0	Jan. '24 = 230.3	Mar. '23 = 216.9
Productivity index, chemicals & allied products (1992 = 100)	Apr. '24 = 92.9	Mar. '24 = 94.1	Feb. '24 = 94.4	Apr. '23 = 93.1

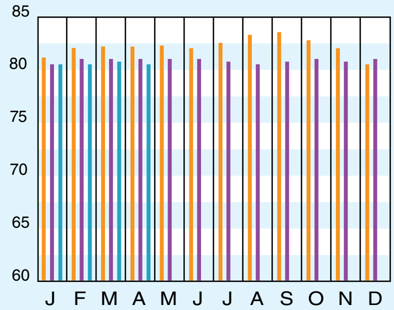
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for April 2024 (most recent available) decreased slightly compared to the previous month, reversing a three-month string of small monthly increases. In April, declines in the Equipment and Buildings subindices offset small increases in the Construction Labor and Engineering & Supervision subindices to arrive at the overall decrease in the CEPCI. The current CEPCI value now sits at 0.5% lower than the corresponding value from April 2023. Meanwhile, the Current Business Indicators (middle) show a small increase in the CPI output index and small decrease in the CPI operating rate for April 2024. The CPI value of output for March 2024 was slightly higher than the Feb. value.